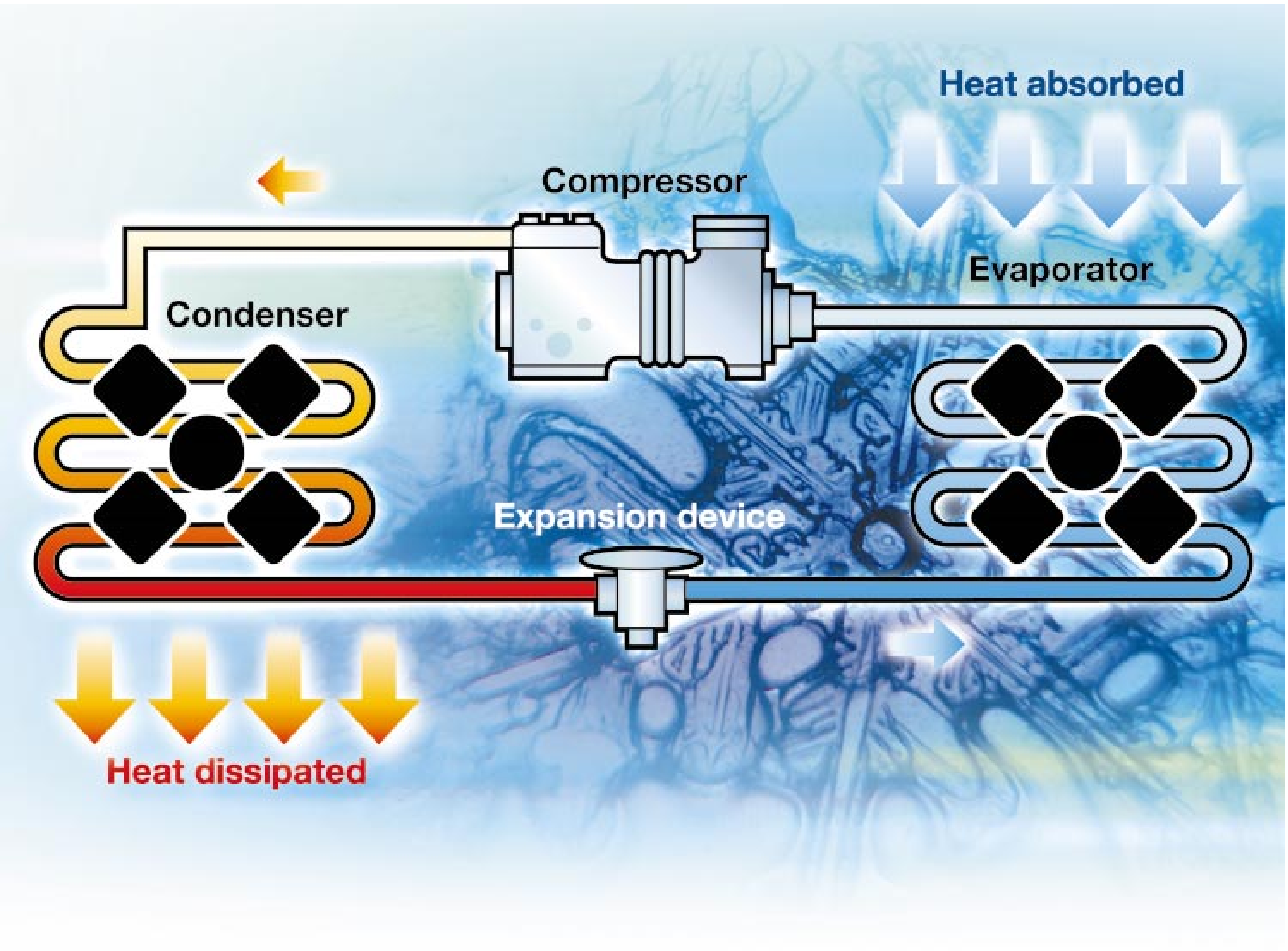
GOOD PRACTICE GUIDE 280

Energy efficient refrigeration technology – the fundamentals



ENERGY EFFICIENCY

BEST PRACTICE PROGRAMME

GOOD PRACTICE GUIDE 280

ENERGY EFFICIENT REFRIGERATION TECHNOLOGY – THE FUNDAMENTALS

Prepared for the Energy Efficiency Best Practice Programme by:

ETSU
Harwell
Didcot
Oxfordshire
OX11 0RA

and:

Safety Services Refrigeration
Cool Concerns

First published January 2000

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FOREWORD

This Guide is part of a series produced by the Government under the Energy Efficiency Best Practice Programme. The aim of the programme is to advance and spread good practice in energy efficiency by providing independent, authoritative advice and information on good energy efficiency practices. Best Practice is a collaborative programme targeted towards energy users and decision makers in industry, the commercial and public sectors, and building sectors including housing. It comprises four inter-related elements identified by colour-coded strips for easy reference:

— *Energy Consumption Guides:* (blue) energy consumption data to enable users to establish their relative energy efficiency performance;

— *Good Practice Guides:* (red) and *Case Studies:* (mustard) independent information on proven energy-saving measures and techniques and what they are achieving;

— *New Practice projects:* (light green) independent monitoring of new energy efficiency measures which do not yet enjoy a wide market;

— *Future Practice R&D support:* (purple) help to develop tomorrow's energy efficiency good practice measures.

If you would like any further information on this document, or on the Energy Efficiency Best Practice Programme, please contact the Environment and Energy Helpline on 0800 585794. Alternatively, you may contact your local service deliverer – see contact details below.

ENGLAND

London
Govt Office for London
6th Floor
Riverwalk House
157-161 Millbank
London
SW1P 4RR
Tel 020 7217 3435

East Midlands
Energy and Environment Team
Govt Office for the East Midlands
The Belgrave Centre
Stanley Place
Talbot Street
Nottingham
NG1 5GG
Tel 0115 971 2476

North East
Environment and Energy Efficiency Team
Govt Office for the North East
Wellbar House
Gallowgate
Newcastle-upon-Tyne
NE1 4TD
Tel 0191 202 3614

North West
Energy and Environment Unit
Govt Office for the North West
Washington House
New Bailey Street
Manchester
M3 5ER
Tel 0161 952 4282

South East
Energy and Environmental Management Unit
Govt Office for the South East
Bridge House
1 Walnut Tree Close
Guildford
Surrey
GU1 4GA
Tel 01483 882316

East
Environmental and Energy Awareness Branch
Govt Office - Eastern Region
Heron House
49-53 Goldington Road
Bedford
MK40 3LL
Tel 01234 796194

South West
Energy and Environmental Management Branch
Govt Office for the South West
The Pithay
Bristol
Avon
BS1 2PB
Tel 0117 900 1700

West Midlands
Environment and Energy Management Office
Govt Office for the West Midlands
77 Paradise Circus
Queensway
Birmingham
B1 2DT
Tel 0121 212 5300

Yorkshire and the Humber
Environmental and Energy Office
Govt Office for Yorks and the Humber
PO Box 213
City House
New Station Street
Leeds
LS1 4US
Tel 0113 283 6376

Merseyside
Transport and Environment Team
Govt Office for Merseyside
Cunard Building
Pier Head
Liverpool
L3 1QB
Tel 0151 224 6402

NORTHERN IRELAND
IRTU Scientific Services
17 Antrim Road
Lisburn
Co Antrim
BT28 3AL
Tel 028 9262 3000

SCOTLAND
Scottish Energy Efficiency Office
Scottish Executive
2nd Floor
Meridian Court
5 Cadogan Street
Glasgow
G2 6AT
Tel 0141 242 5835

WALES
Energy and Environment Office for Industry and Training
National Assembly for Wales
Cathays Park
Cardiff
CF1 3NQ
Tel 029 2082 3126

CONTENTS

This Guide is divided into three main Sections:

FIGURES Page No.

INTRODUCTION

In this Guide we introduce you to the energy efficiency fundamentals of refrigeration technology – the concepts and the factors that will help you to buy, design, install or service a good system. This Guide assumes no prior knowledge of refrigeration.

This Guide complements the Good Practice Guides (GPGs), Case Studies and other Energy Efficiency Best Practice Programme publications for the refrigeration sector.

The following topics are covered:

- basic theory – how a refrigeration system works using simple scientific principles;
- the components – their function and variations;
- common applications with example systems.

There is great scope for improving the energy efficiency of refrigeration systems. As well as reducing energy costs, this almost always has the added benefit of increasing reliability and hence reducing service and downtime costs throughout the plant's lifetime. For more information about how to apply the basic principles outlined in this Guide, you should refer to the Good Practice Guides listed at the front of this Guide.

Improving energy efficiency saves money, and usually also improves the reliability of refrigeration systems. The information in this booklet helps you understand energy saving technology – important information if you own, design or service refrigeration plant.

Throughout this Guide:

A triangle is used to show information that is very important for energy efficiency.

A signpost is used to show you where you can find more detailed information about a topic, elsewhere in this Guide, or in another publication.

1 BASIC REFRIGERATION AND ENERGY EFFICIENCY

This Section starts with some basic rules of heat transfer, and then describes how a refrigeration system works using two different explanations. The first uses thermodynamics and the second uses hardware. This is followed by the key factors that affect the efficiency of a refrigeration system.

1.1 The refrigeration process explained

A refrigeration system transfers heat from a substance to be cooled to another area (usually outside air). Most refrigeration systems use the vapour compression cycle. Heat is absorbed through a heat exchanger as the refrigerant evaporates, for example, in the fan coil unit in a cold store. Heat is rejected through another heat exchanger as the refrigerant condenses.

See GPG 256
An introduction to absorption cooling

There are other types of system which can be used to obtain a cooling effect, for example the absorption refrigeration system, which can be effective when there is plenty of waste heat available. GPG 256, *An introduction to absorption cooling* covers applications of absorption systems.

You may wish to refer to the Glossary of Terms on page 48 to help you with this Section first time through.

You need to know some basic rules of physics to understand the vapour compression cycle:

Rule 1. Heat flows naturally from hot to cold.

Rule 2. Energy (in the form of heat) is required to change a substance from a liquid to a gas (i.e. to boil or evaporate). When this happens the liquid absorbs large amounts of heat. This explains why sweating cools the skin.

Rule 3. Energy is given out by a substance changing from a gas into a liquid (i.e. liquefying or condensing). This explains why steam is particularly good at heating things on which it condenses.

Rule 4. The boiling temperature and the condensing temperature change if the pressure changes – Figure 1 shows this relationship for ammonia and R134a. This principle explains why you can't make good tea up a high mountain – the water boils at only about 90°C because of the lower pressure.

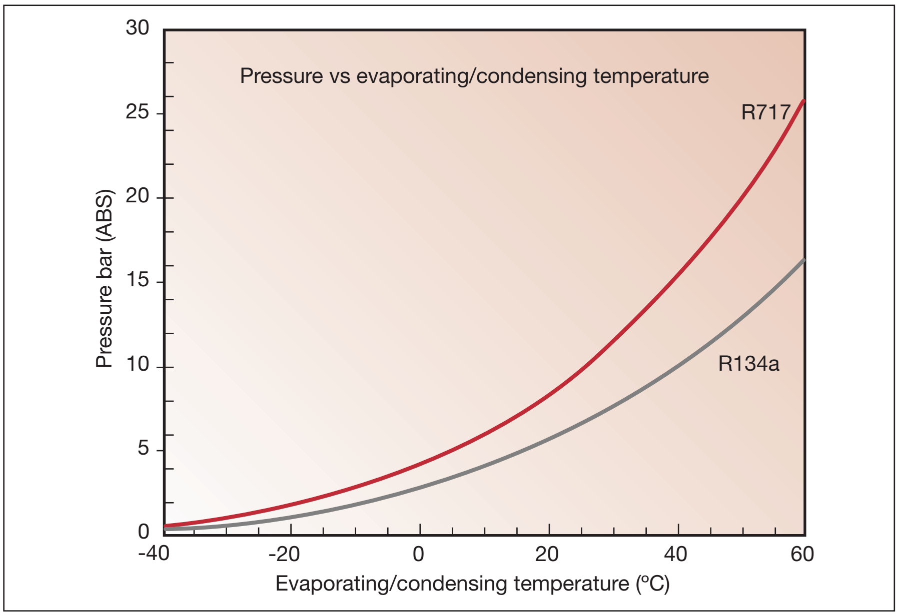


Figure 1 Pressure-temperature relationship for ammonia (R717) and R134a

The refrigeration system uses a fluid – the refrigerant – which boils at a low temperature (usually between -10°C and -45°C) when it is at a low pressure (the saturation pressure, usually between 1 and 5 bar as shown in Figure 1). Its boiling or evaporating pressure can be controlled so that it boils at a temperature lower than that of the product to be cooled (e.g. ice cream) – Rules 4 and 1.

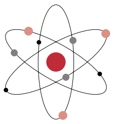
Note: Because the temperature and pressure of a refrigerant are related so closely, the terms are often used interchangeably. You will hear people talk of a condensing temperature of X°C, and of a condensing pressure of Y bar – these are alternative ways to describe the same physical state of a particular quantity of refrigerant. It's a bit like a chocolate bar on a Channel ferry costing £1.10 or 11 Francs – there is a standard way to convert between the two, and different people prefer different measures. In this Guide, we have standardised on using condensing temperature/evaporating temperature.

Product is usually cooled indirectly (as shown in Figure 2) – the refrigeration system cools air, or a liquid known as a secondary refrigerant, which in turn is used to cool the product. The product, via the cooling medium (air or the secondary refrigerant), provides the energy to evaporate the refrigerant – Rule 2.

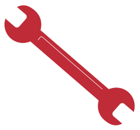
The refrigerant vapour is then compressed to a higher pressure. Its saturated temperature is then higher than the ambient air or water used to remove the heat from the refrigerant. The consequent heat loss converts the vapour back into a liquid – Rule 3. The ambient air or water will, as a consequence, warm up.

The liquid returns to the evaporator via a pressure-reducing device.

Two explanations follow that show how a refrigeration system works.



The first is a 'thermodynamics-based' explanation, using a refrigerant pressure/enthalpy chart.



The second is a 'hardware-based' explanation describing what happens in the components of a refrigeration system. This explanation also includes some information about factors which affect the performance of a component and/or the system as a whole.

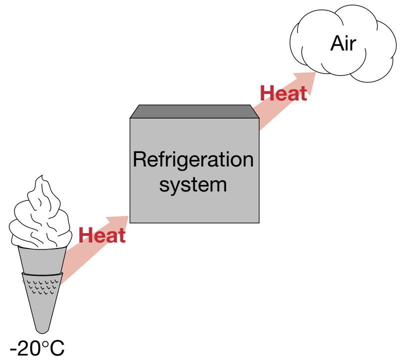


Figure 2 Refrigeration heat transfer

How a refrigeration system works – the thermodynamics

The operation of a simple system is shown in Figure 3 which shows the pressure-enthalpy chart for a typical refrigerant. The enthalpy (energy content) of the refrigerant varies with its pressure, temperature and state. The curve is the saturation curve:

- On the left part of this curve, the refrigerant is just a pure (saturated) liquid.
- On the right part, it is a pure (saturated) vapour.
- Inside the curve the refrigerant is a saturated mixture of liquid and vapour.
- In the area to the left of the curve the refrigerant is a sub-cooled liquid (i.e. a liquid below its saturation temperature).
- In the area to the right of the curve it is a superheated vapour (i.e. at a temperature above its saturation temperature).

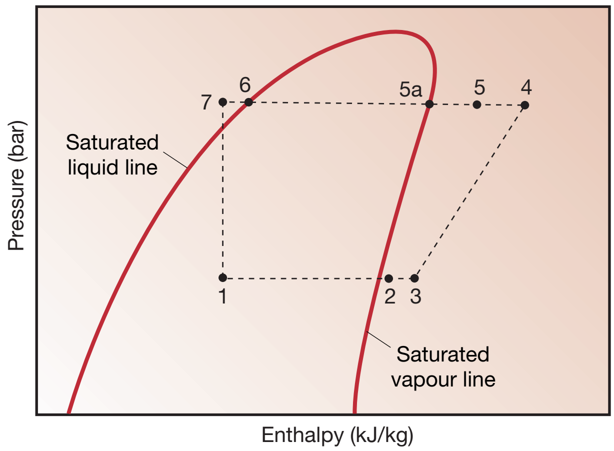


Figure 3 Simple pressure-enthalpy diagram for a typical refrigerant

The refrigeration cycle can be broken down into the following stages:

1 → 2 Low pressure liquid refrigerant (1) in the evaporator absorbs heat energy from its surroundings (usually air, water or some other process liquid), which fuels its change of state from a saturated liquid to a saturated vapour. In certain systems, at the evaporator exit (2) the refrigerant vapour is slightly superheated as shown.

2 → 3 The slightly superheated refrigerant vapour picks up more heat energy from ambient air around the pipework between the evaporator and the compressor. This is bad for efficiency.

3 → 4 The superheated vapour enters the compressor where its pressure is raised. There will also be a large increase in temperature, because some of the energy of compression is transferred into the refrigerant purely as heat, thus raising its temperature (superheat).

4 → 5 The very hot vapour loses a small amount of heat to ambient air in the pipework between the compressor and condenser. This is good for efficiency.

5 → 6 The high pressure superheated vapour flows into the condenser. The initial part of the cooling process (5 → 5a) de-superheats the vapour before it then turns back into saturated liquid (5a → 6). The cooling for this process is usually achieved by using ambient air or water.

6 → 7 A further reduction in temperature may occur between the condenser and the expansion device, so that the refrigerant liquid is sub-cooled as it enters the expansion device. This is good for efficiency.

7 → 1 The high pressure sub-cooled liquid passes through the expansion device, which reduces its pressure and results in the temperature of the refrigerant going down. There is, however, no energy loss or gain through the expansion device.

The outlet of the expansion device/inlet to the evaporator does not lie on the saturated liquid line. This is because, at the lower temperature, the refrigerant cannot contain as much heat. This excess heat causes some of the refrigerant to evaporate (flash off) in expanding.

How a refrigeration system works – the hardware

The operation of the main system components is shown in Figure 4 and briefly described below. All systems must contain these components. More detailed information on the type and variation of these components is given in Section 1.2.

1 → 2 Refrigerant absorbs a lot of heat in the evaporator

The evaporator contains refrigerant boiling at low pressure. As the refrigerant boils or evaporates it absorbs a lot of heat. This heat is removed from whatever surrounds the evaporator, usually air or a secondary refrigerant. For example, in cold stores and cabinets, heat is removed from the air (the air is cooled) by the evaporating refrigerant. The cooled air is circulated around the food.

See evaporators page 9

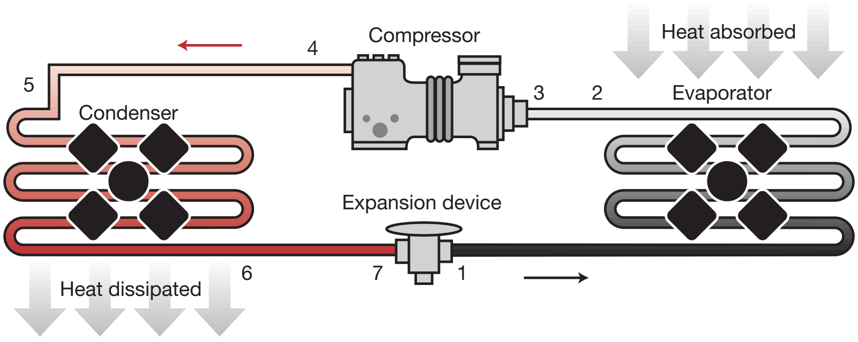


Figure 4 Schematic diagram of a simple refrigeration system

The cooling effect of the evaporator is governed by:

- The difference in temperature between the medium being cooled and the evaporating refrigerant. The wider the temperature difference the greater the rate of heat transfer.
- The size and design of the evaporator.

Different types of evaporator are used for air cooling and for cooling a liquid.

2 → 3 Refrigerant vapour absorbs a little more heat in the suction line

The refrigerant absorbs heat from the ambient temperature air around the suction line between the evaporator and the compressor. This superheating should be minimised by insulation, to maintain efficiency.

3 → 4 Refrigerant vapour is compressed in the compressor

See compressors page 14

The compressor compresses refrigerant vapour from the low pressure of the evaporator to the higher pressure of the condenser. During compression, the refrigerant vapour also heats up.

Compressors are usually driven by an electric motor and are the main power users in refrigeration systems.

The compressor capacity is affected by:

- The compressor displacement, usually measured in cubic m/s (m^3/s).
- The difference between the evaporating and condensing temperature – also known as the temperature lift. This is similar to the compression ratio – the pressures in the evaporator and condenser are related to the evaporating and condensing temperatures.
- The temperature of the superheated suction vapour.
- The properties of the refrigerant.

There are a number of compressor types available with different enclosures and compression parts.

4 → 5 Refrigerant vapour loses some heat in the discharge line

The high pressure refrigerant vapour flows from the compressor to the condenser, losing a small amount of heat energy to ambient air. This should be maximised for best efficiency.

5 → 6 Refrigerant loses a lot of heat in the condenser

The condenser contains refrigerant which is changing from a superheated vapour into a liquid at high pressure. A lot of heat energy is released during this process, which is either rejected to ambient air or to cooling water.

See condensers page 19

The condenser capacity is affected by:

- The temperature of the cooling air or water.
- The size and design of the condenser.

6 → 7 Liquid refrigerant subcools in the liquid line

The liquid refrigerant flowing between the condenser and expansion device usually loses heat to ambient air. This subcooling is beneficial to the performance of the system since it increases refrigeration capacity without increasing the power input.

7 → 1 Refrigerant pressure is dropped in the expansion device

An expansion device maintains the pressure drop between the condenser and evaporator. The refrigerant saturation temperature also reduces as the pressure drops.

The expansion device is sized to pass the required amount of refrigerant at the minimum likely pressure drop across the system.

1.2 Key factors that affect efficiency and Coefficient of System Performance (COSP)

The refrigeration load

The cooling load on the refrigeration system determines the size of the refrigeration plant and therefore its power consumption. (It does not affect COP or efficiency: without a refrigeration load there would be no COP or efficiency.)

The smaller the load, the lower the power consumption.

The load is usually made up of a number of different components. You may be able to be reduce or eliminate one or more of these.

In a storage application (e.g. a cold store or retail cabinet) the load comprises:

- heat gains through walls, floor and ceiling;
- heat gains from air changes through doors/lids/open fronts;
- heat from fan motors, lights and even solar radiation;
- heat from pumps and other electrical devices in the cold store;
- heat from people and handling equipment, such as fork-lift trucks, which enter the store;
- possible heat load from product entering which is at a higher temperature than the storage temperature.

You pay for some of these heat gains twice. For example, you pay to run the evaporator fan motor, but you also pay for the refrigeration system to remove the heat this puts into the cooled space.

In processing applications, the majority of the heat load is usually from the product that is being cooled or frozen, although there may be extraneous heat gains as well.

Reducing cooling loads see GPG 279

More information about reducing these heat loads is given in GPG 279 *Cutting the cost of running your refrigeration plant*.

COP and COSP

The energy efficiency of a refrigeration system is expressed as the Coefficient of System Performance (COSP).

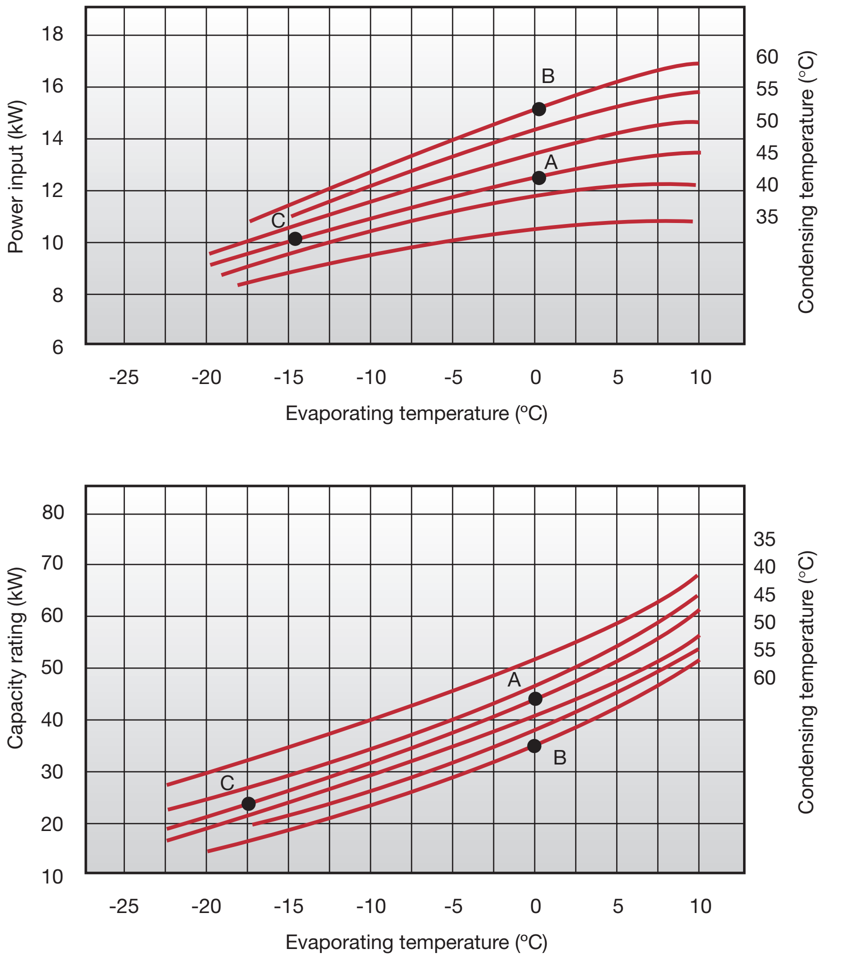
$$\textbf{COSP} = \frac{\textbf{capacity (kW)}}{\textbf{power (kW)}}$$

The power input is that of the compressor and all other motors (e.g. fan motors and pumps and controls) associated with the system.

Efficiency can also be expressed as COP – this is just the efficiency of the compressor, it does not take into account the power input of other electrical components such as fan motors and pumps.

The COP varies depending on the temperature lift of the system – the temperature lift is the difference between the evaporating and condensing temperatures. The example data in Figure 5 show that:

- the capacity of the compressor increases when the temperature lift reduces;
- the compressor power input decreases when the condensing temperature is lowered;
- the compressor power input increases when the evaporating temperature is increased, but the increase in power input is not as great as the increase in capacity (hence the COP still goes up).



A to B is raising the condensing temperature, A to C is lowering the evaporating temperature; both of these mean higher temperature lift, and both reduce the system capacity.

The COP is greater at lower temperature lifts.

Figure 5 Typical compressor performance curves

The temperature lift reduces if:

- the condensing temperature is lowered;

  and/or

- the evaporating temperature is raised.

An increase of 1°C in evaporating temperature or a reduction of 1°C in condensing temperature will increase the compressor COP by 2 – 4%.

Or put another way:

A decrease of 1°C in temperature lift will cut running costs by 2 – 4%.

The condensing temperature will be lower if:

- A condenser with a high basic rating is used (this is usually a larger condenser).
- The condensing temperature is allowed to float down with the ambient temperature. The average ambient temperature in the UK is about 10°C – taking advantage of this rather than holding the condensing temperature artificially high saves a significant amount of energy – probably in excess of 25% for many systems.

See lowering condensing temperature page 19

- Water is used instead of air as the condenser cooling medium (but don't forget to include the fan motors and pumps associated with water-cooled condensers and cooling towers in your COSP calculation).

It is also important that condensers do not become blocked, or their flow of cooling air or water becomes impeded in any other way.

The evaporating temperature will be increased if:

See evaporating process page 9

- An evaporator with a higher basic rating is used (this is usually a larger evaporator).
- The evaporator is defrosted when necessary.

When the evaporating temperature of an evaporator cooling air is below 0°C, ice will build up on the coil block. This must be regularly removed through an effective defrost procedure. It is also important to ensure the evaporator is clean.

Other factors also affect the COP of the system:

See compressor efficiency page 18

- The efficiency of different compressor types and manufacturers varies, and not necessarily according to price – it is important that the most efficient compressor for a particular application is carefully selected. This depends on the size of the cooling load, the refrigerant used, the temperature of the application and the average temperature of the cooling medium (i.e. ambient air or water).
- The amount of refrigerant has a significant effect on temperature lift – too much or too little refrigerant charge reduces efficiency. **Systems that leak refrigerant consume more power than necessary. On average this costs UK refrigeration plant owners an extra 11% on the running costs of their systems.** Systems that are overcharged can, in certain cases, also consume more power than necessary and have more refrigerant to lose in the case of a leak.

See refrigerant type page 27

- The refrigerant type also has an effect on energy use. The variation can be as high as 10%, but this benefit can only usually be achieved when the hardware is optimised to suit the refrigerant chosen. The most efficient refrigerant for an application depends on the compressor used, the temperature of the application and the average temperature of the cooling medium (i.e. ambient air or water).
- The superheat of the suction vapour should be as low as possible – warmer vapour reduces the capacity of the compressor without reducing its power input. On direct expansion systems, this is achieved by correctly controlling the expansion device, and on all system types, by insulating the suction line.
- The amount of subcooling of the liquid refrigerant entering the expansion device should be as high as possible – this increases the capacity of the system without increasing power input. The liquid line should not be insulated and should not pass through hot areas (e.g. kitchens or direct sunlight).

SYSTEM COMPONENTS AND REFRIGERANTS

2

This Section includes descriptions of the common components used in refrigeration systems, and outlines the high efficiency issues associated with the main components:

2.1 Evaporators

Different evaporators are used for different applications. Particular differences will occur between these for cooling air or for cooling liquid. The most common types are described below. An explanation of the evaporating process is given below.

The evaporating process

Refrigerant liquid passes through the expansion device, dropping in pressure and temperature, and then enters the evaporator where it absorbs heat from the 'hotter' tubes and, therefore, begins to evaporate (boil). This creates the cooling effect, as the heat absorbed from the tubes is, in turn, absorbed from the air or liquid flowing around the evaporator tubes, thus chilling it. Some refrigerant may, during expansion, evaporate instantly – this is called flash gas, and will also often occur in the pipework between the expansion device and the evaporator and, therefore, may not provide any useful cooling.

Once in the evaporator, the refrigerant boils off progressively along the evaporator at the evaporating temperature, turning from a liquid to a saturated vapour at the same temperature. Only when the evaporation process is finished, and the refrigerant at that part of the evaporator is 100% vapour, does its temperature rise further.

This further heating above the saturated evaporating temperature is called superheating. Some superheating, as a safety margin, is necessary in direct expansion (DX) systems to ensure that no liquid refrigerant can return to the compressor. However, superheating is not a very efficient use of the evaporator – much more heat is absorbed during the boiling process (latent heat) than is absorbed by a vapour changing temperature (sensible heat). A sensible balance must be found – superheat should usually be set to around 5°C above the evaporating temperature.

The evaporating process is illustrated in Figure 6. Figure 7 shows how the temperature changes for the refrigerant.

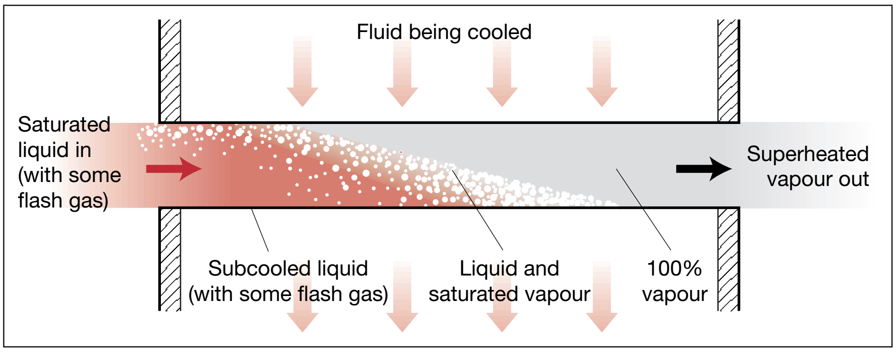


Figure 6 Refrigerant flow in an evaporator tube (not to scale – diagrammatic only)

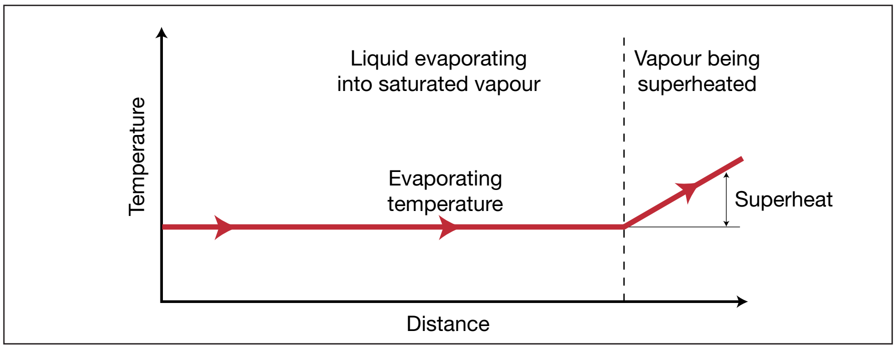


Figure 7 Temperature graph of the refrigerant as it flows along the evaporator (shown for the case of a single substance, not a blend)

Direct expansion (DX) air coolers

Most of these use finned tubes, usually with forced circulation of air. A typical finned tube evaporator will have a number of parallel circuits designed to:

- maximise heat transfer;
- ensure good oil return;
- minimise pressure drop.

A distributor is used to ensure refrigerant flows evenly between the different parallel circuits. Figure 8 shows an evaporator with a distributor.

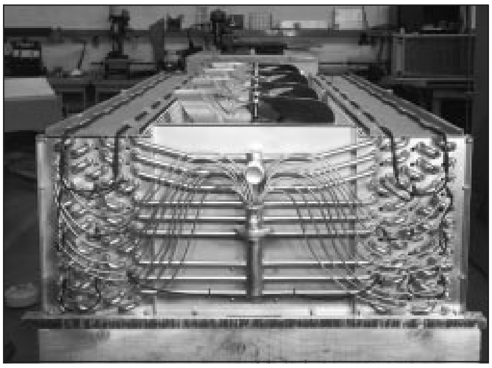


Figure 8 Evaporator with a distributor for more even refrigerant flow

Saturated refrigerant is fed through the distributor into the evaporator tubes where it is totally evaporated before reaching the outlet. By controlling the flow of refrigerant, the expansion device ensures the refrigerant leaving the evaporator is superheated a little (usually by about 5K). This ensures that the refrigerating effect is as high as possible while still protecting the compressor from liquid refrigerant returning down the suction line.

Small systems with a capillary tube have a simpler evaporator. The quantity of refrigerant charge is critical to ensure efficient evaporation and to prevent liquid flooding into the compressor.

Defrosting direct expansion evaporators

Ice will build up on the evaporator and so decrease efficiency when the evaporating temperature is below 0°C (which it will be for most refrigeration applications). There are three ways the ice can be removed:

- natural defrosting if the air temperature is above 4°C – when the refrigeration system is off the fans remain running to allow the air to defrost the fin block;
- electric defrosting – defrost heaters, embedded in the fin block, are periodically switched on to defrost the fin block while the compressor is switched off;
- hot or cool vapour defrosting – hot discharge vapour or warm saturated vapour from the top of the receiver is circulated through the evaporator to melt the ice.

In all cases there is a drain pan and line to allow the condensate to drain away. When the air temperature is below 0°C, these are heated and insulated.

Energy efficient defrosting depends on the following factors:

- initiating a defrost operation only when it becomes necessary through detectable loss of performance;
- using the most efficient method of applying the necessary heat;
- ensuring that the defrost heat is evenly distributed over the whole of the fin block;
- stopping the defrost cycle as soon as the fin block is totally clear of ice;
- minimising the amount of defrost heat absorbed by the process fluid or product;
- minimising the frost build-up by ensuring the evaporating temperature is as high as possible and there is low humidity around the evaporator.

Defrost on demand (where sensors are used so that defrost is initiated only when necessary and terminated just when the fin block is clear of ice) is always more efficient than timed defrosting, as it adjusts to the varying levels of ice build-up that will usually occur.

Flooded or pumped liquid air coolers

Flooded air coolers require locally mounted surge drums from which liquid refrigerant is gravity-fed to the coils of the unit. With pumped circulation units, a single remote mounted drum can serve a number of coolers. Rotary pumps distribute the liquid refrigerant to the units. Both methods of liquid supply achieve a fully wetted heat transfer surface, giving an increase in capacity over a direct expansion-type cooler.

With flooded or pumped circulation coolers, a higher evaporating temperature than that used with direct expansion-type units can be achieved as no unnecessary superheat is required to prevent liquid flooding to the compressor.

Shell and tube liquid coolers – flooded-type

These are commonly used in larger applications. The fluid to be cooled is passed through the tubes, with the evaporating refrigerant boiling off into vapour within the body of the shell. The refrigerant level in the shell is maintained so that the top tube is always covered with liquid. In this way, the most efficient heat exchange, liquid to liquid, is achieved over the whole of the cooling interface. Figure 9 is an example of this type of evaporator.

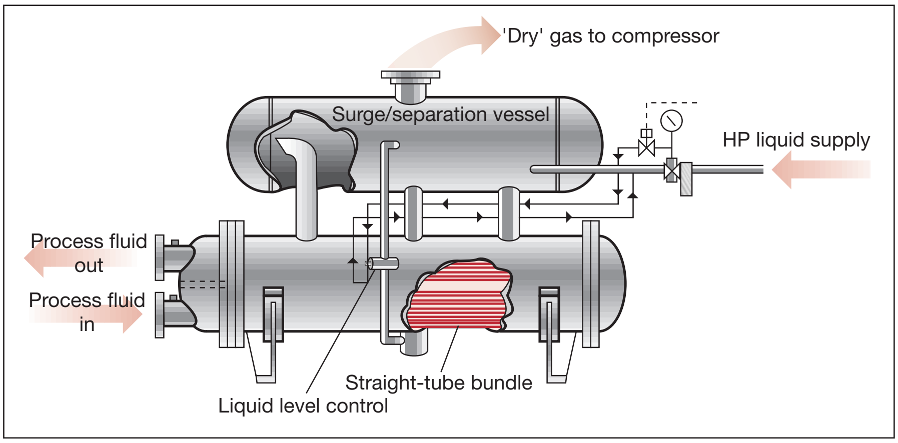


Figure 9 Shell and tube evaporator

See low pressure float valve page 26

To ensure optimum efficiency, the liquid level is usually maintained by using a low pressure float valve – see Section 2.4 for more details. Alternatively, an expansion device and level sensor can be used.

The space in the upper part of the shell allows any droplets of liquid to be separated from the vapour returning to the compressor. This separation is sometimes achieved in a different vessel called a surge drum.

Shell and tube liquid coolers – direct expansion-type

With a direct expansion shell and tube liquid cooler, the refrigerant is metered into the tubes by a thermostatic expansion valve. The process fluid flows through the shell side of the unit, over the tubes, between baffles that ensure the fluid is in ‘cross flow’ to the refrigerant flow.

To achieve a fully wetted surface in the evaporator, the expansion valve sensing phial is sometimes located downstream of a suction to liquid line heat exchanger. The refrigerant vapour is superheated in this heat exchanger (by the liquid refrigerant), rather than in the evaporator, thus increasing the capacity of the evaporator.

Figure 10 Plate heat exchanger

Plate heat exchanger liquid coolers

In a plate heat exchanger, the refrigerant and the fluid to be cooled flow through channels formed in an assembly of corrugated plates, either brazed or bolted together, as shown in Figure 10. Plate heat exchanger evaporators can operate on either the flooded principle or by direct expansion. Most suppliers offer a surge drum to separate liquid and gas with the flooded-type.

The advantages of plate heat exchanger liquid coolers over shell and tube evaporators are:

- higher heat transfer coefficients;
- a smaller temperature difference between the refrigerant and the cooled liquid, resulting in higher evaporating temperatures and, therefore, improved system efficiency;
- more compact units requiring less plant room space;
- smaller refrigerant charge;
- the ability to clean non-brazed assemblies, thus maintaining a good heat transfer capability.

Baudelot liquid coolers

This type of cooler is used to cool down a fluid, most commonly process water, close to freezing temperature, usually to within 0.5°C of the freezing point. The Baudelot cooler is designed so that it will not be damaged if the water freezes.

The usual type has the water running down in a thin film over the outside of the refrigerant tubes or plates (see Figure 11) and collected in a storage tank at the base. Several designs are used, with either the refrigerant coil wound from steel tube (and then galvanised), or vertically embossed stainless steel plates.

Figure 11 Baudelot cooler

Oil control in evaporators

Compressor lubricating oil flows around the system with the refrigerant. It is important that this oil returns to the compressor, but it can drop out of solution with the refrigerant in the evaporator. Oil control in evaporators is, therefore, an important issue.

In order to maintain the optimum system efficiency, it is important that oil is not allowed to collect in the evaporator where it will coat the tubes and reduce heat transfer.

In direct expansion evaporators an adequate refrigerant velocity must be maintained to carry the oil through both the tube assembly and suction line and thus return it to the compressor at all load conditions. With flooded evaporators the oil can be removed if necessary – the method will depend on the refrigerant.

Evaporator efficiency issues

The evaporating temperature must be as high as possible to maintain evaporator efficiency. Using a large evaporator achieves this, but in addition:

- in a direct expansion air cooler the fin block should be kept clear of dirt and slime and adequately defrosted if necessary;
- the tubes in a shell and tube evaporator should be cleaned to prevent fouling and corrosion (water may need to be treated to reduce such problems);
- the cooling medium flow should be maintained – pump and fan motors must work;
- oil should not be allowed to build up in the evaporator;
- the flow of refrigerant through the evaporator should be correctly controlled to ensure full use of its capacity with minimum superheat.

2.2 Compressors

The purpose of the compressor is to draw the low-pressure refrigerant vapour from the evaporator and compress it to a higher pressure. This enables the vapour to be condensed back into liquid by some convenient low-cost source of cooling, such as ambient air or water.

Types of compressor housing

Most compressors are driven by an electric motor:

Either hermetic/semi-hermetic:

- Built into the same housing as the compression parts. Hermetic compressors are built into a welded shell, and there is no access to the internal parts for servicing or repair. Semi-hermetic compressors are assembled with removable covers, usually sealed by gaskets, enabling a limited amount of access for on-site service. Hermetic compressors and larger semi-hermetic (above about 8 kW motor power) compressors are usually suction-gas cooled – i.e. the refrigerant cools the motor before compression. This reduces the capacity of the compressor. Externally-cooled types, where the vapour passes directly into the cylinders, are usually about 8% more efficient than the equivalent suction-cooled models.

Or open-type:

See GPG 2 *Energy saving with electric motors and drives*

- With the drive shaft passing through a rotating vapour seal (an open-type). The motor is connected to the external drive shaft either with a direct coupling or via belts. The motor must be accurately sized for the compressor's duty and starting torque requirement. Running a motor below its design duty reduces its power factor and efficiency. When comparing the input power of open and semi-hermetic compressors, the motor's efficiency and drive losses must be taken into account for open drive machines. High efficiency motors are usually available and are now approximately the same price as standard motors (see GPG 2).

Types of compressor

Reciprocating, screw, scroll and centrifugal compressors are all used in commercial and industrial refrigeration. They are outlined in more detail below.

Reciprocating compressors

Reciprocating compressors are the most common type used today.

The suction vapour is compressed by pistons moving in a close fitting bore. The suction and discharge valves are either simple flapper reeds (on smaller compressors) or ring valves (on larger machines). Bearings are lubricated by refrigeration oil from the crankcase.

Reciprocating compressors are commonly available in a very wide range of sizes, from a small, single-cylinder type used in domestic refrigerators, to eight-cylinder models used in industrial applications (although models as large as 24-cylinders are used in a few, very large industrial systems). Figure 12 shows a cutaway of a semi-hermetic reciprocating compressor.

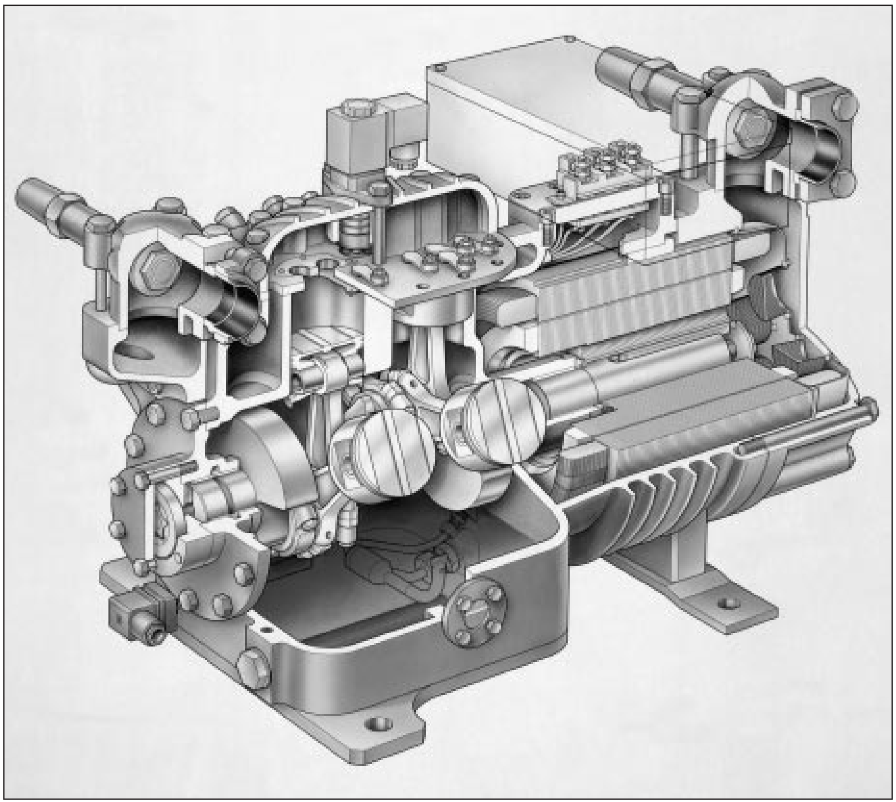


Figure 12 Cutaway diagram of a reciprocating compressor

Capacity control in reciprocating compressors

Larger reciprocating compressors (typically above 7.5 kW nominal motor size) can be supplied with capacity control. This is usually achieved by one of the following methods:

- blocked suction vapour into one or more cylinders (the suction vapour is stopped from entering one or more cylinders, thus reducing the pumping rate of the compressor);
- suction valve lifting (the suction valve is raised, allowing the refrigerant vapour to pass back into the suction chamber during the compression stroke);
- discharge vapour recirculation (vapour discharged from the piston is returned directly to the suction vapour, thus reducing the amount of refrigerant pumped around the system, but not the amount pumped by the compressor).

The latter method is the least efficient – the power input to the compressor is usually the same on part-load as it is on full-load. With the other methods the power input falls almost in line with the capacity reduction.

Screw compressors

The most widely used types of screw compressor are the oil-injected twin-rotor machine (Figure 13) and the single screw machine in which a main rotor meshes with two diametrically opposed star wheels (Figure 14).

See applications of screw compressors page 46

The screw compressor is a positive displacement machine with the ability to operate over much higher pressure ratios than those of a reciprocating machine. They are, by virtue of their few moving parts, ideally suited for arduous duties calling for extended running under heavy loads. Unlike the reciprocating machine, the screw machine operates on a specific internal pressure ratio determined by its physical construction/geometry.

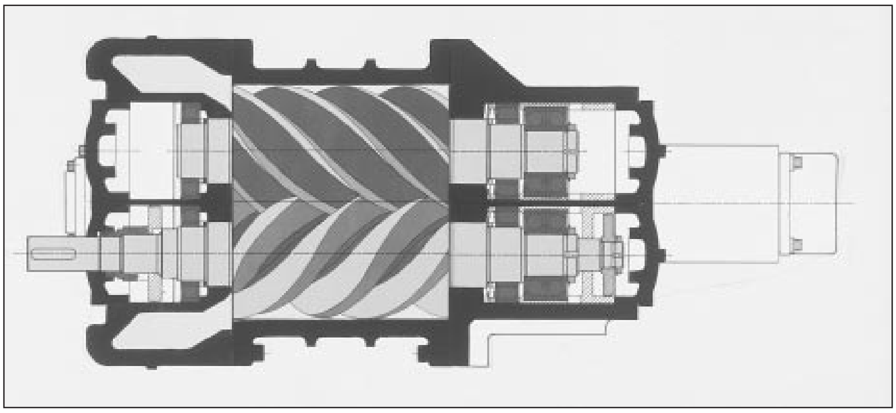


Figure 13 Cutaway diagram of a twin-rotor screw compressor
Courtesy of Howden Compressors Ltd

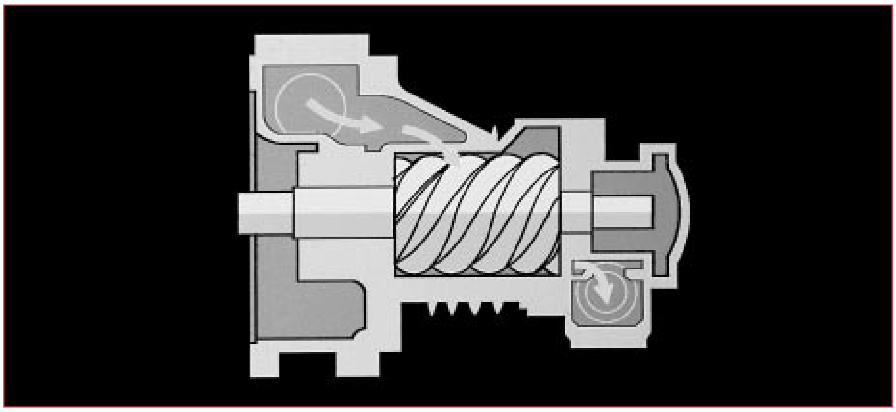


Figure 14 Cutaway diagram of a single-screw compressor

For optimum efficiency, the internal pressure ratio determined by the volume ratio of the compressor should match the 'external' pressure ratio existing across the refrigeration systems. Modern screw compressors have the ability to continually adjust their internal geometry to provide a volume ratio which results in the internal pressure ratio matching exactly the external pressure ratio under varying head pressures.

Screw compressors are cooled by oil that is injected into the machine to seal running clearances between rotors and casing. It absorbs a significant amount of the heat of compression. For optimum efficiency the oil is cooled externally to the machine in a shell and tube heat exchanger cooled by water or refrigerant or by thermo-syphon cooling. Cooling by direct injection of refrigerant into the compressor reduces available capacity of the machine with a corresponding loss in efficiency.

Capacity control in screw compressors

The capacity of the screw compressor is controlled by adjusting the degree of opening of a slide valve positioned in the housing encasing the rotors. With this valve closed (100% capacity) all vapour entering the machine is compressed and discharged to the condenser. With the valve fully open (minimum capacity) approximately 90% of the vapour is allowed to flow directly back to suction uncompressed. Due to the internal losses of the screw compressor (proportional more to speed than capacity) part-load operation below 60% is relatively inefficient. Figure 15 shows the variation in power over the capacity range of a typical screw compressor operating with a ratio of condensing to evaporating pressure of 4:1.

Variable speed drive is now available as a method of controlling the capacity of a screw compressor giving improved efficiency at part-load conditions.

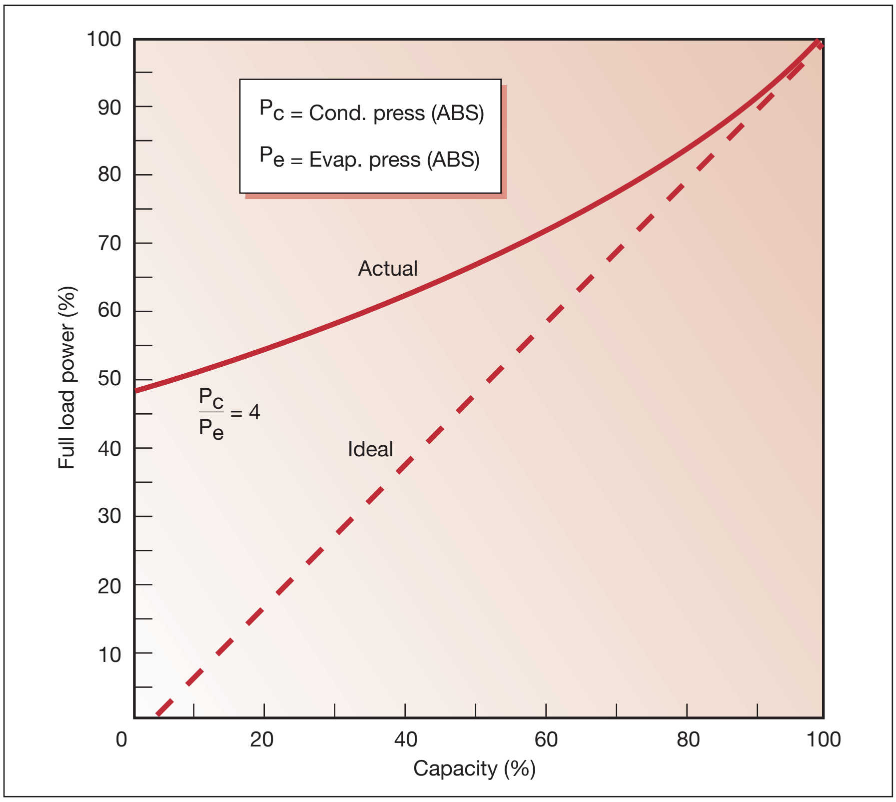


Figure 15 Graph of losses for typical screw compressor, contrasting the ideal (theoretical) with what occurs in practice

Scroll compressors

This type of compressor has two scroll components – one fixed and the other orbiting. Refrigerant is progressively compressed as one scroll orbits. High pressure refrigerant is continually discharged from the compressor. Scroll compressors are hermetic types as shown in Figure 16.

The size range of scroll compressors is limited (they are widely available up to 12kW motor size) – they are most likely to be used on small to medium-sized commercial refrigeration applications such as cold stores, milk tanks, beer cellars, appliances and supermarket packs.

Many scroll compressors are of the compliant type. These allow some movement of the scroll radially and/or axially. They are, therefore, tolerant to some liquid return and particle contamination. Scroll compressors are quieter and vibrate less than reciprocating types. At high evaporating temperatures (typically above 0°C) they are usually more efficient than reciprocating compressors, but this is not the case for low-temperature applications.

Figure 16 Cutaway model of a scroll compressor

Centrifugal compressors

Where large volumetric flows of refrigerant are needed, such as in large capacity water chillers, centrifugal compressors are often used. Where wide variations in load occur, the most common methods of capacity control are inlet valve throttling or discharge to suction bypass. Both reduce efficiency.

These machines are usually specially selected and matched to evaporators and condensers by the manufacturer, then supplied pre-assembled on a skid (a packaged chiller). The machines are usually specified by the conditions required in the fluid (usually chilled water). If operation at reduced loads for long periods is expected, the manufacturer can take it into account when specifying the machine, and mitigate the efficiency losses described above.

Compressor performance data

Figure 5 (page 7) shows a typical data sheet for a compressor. It shows how the capacity and power vary over the range of evaporating and condensing temperatures. This could also be represented as in Figure 17 as COP data.

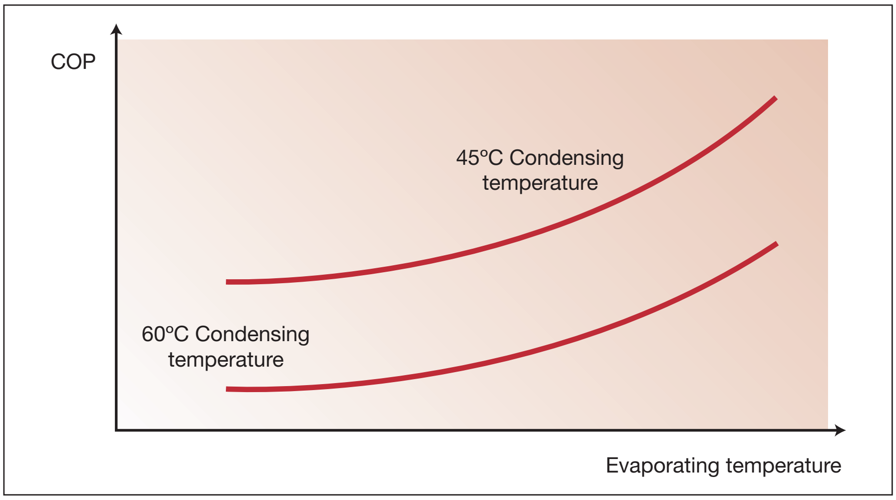


Figure 17 COP data for a typical compressor derived from performance data in Figure 5

The data are presented at specific suction and liquid conditions (the rating point). These rarely match the conditions of a real system, so correction factors must be used to calculate the accurate capacity and power input for a specific application. Computer software provided by compressor suppliers makes this easier.

When comparing different compressors, the rating conditions should be the same. To make an accurate comparison of the performance of various compressors, the most prevalent operating conditions that the system will work at should be used – this is rarely the 'design' condition.

Compressor efficiency issues

The efficiency of the different compressor types varies significantly, so accurate comparisons are necessary to find the most appropriate for a particular application. Some compressors need ancillaries which absorb power, such as cooling fans. These should be taken into account when making comparisons.

For applications which have a large load, it is usually most efficient to split up the load between smaller compressors using a control system to match the total compressor capacity to the load. If the compressors are unevenly sized, the degree of capacity control is increased. More frequent starting and stopping as a result of matching the capacity of an oversized compressor to a load can erode efficiency and can reduce reliability.

Operation on in-built capacity control should be avoided or minimised wherever possible. This can be achieved by:

- avoiding the use of a single, large compressor;
- selecting a combination of compressor sizes which avoids the need for operation of one or more machines on capacity control;
- where multiple compressors are used, using a control strategy which minimises the operation of compressors on part-load (in particular, does not allow two compressors to operate on 50% capacity rather than one compressor on 100% capacity).

More information is given in General Information Leaflet 52 *The engine of the refrigeration system: selecting and running compressors for maximum efficiency* and in GPG 283 *Designing energy efficient refrigeration plant.*

Further guidance on compressors see GIL 52 and GPG 283

2.3 Condensers

Condensers	Page

The condensing process

Superheated refrigerant vapour enters the condenser, where it loses heat by passing close (i.e. the thickness of a tube wall) to a coolant fluid. The coolant may be air, water or other fluids. The refrigerant vapour is first cooled to its saturation temperature (dependent on the pressure of the vapour) at which point condensation begins. As it condenses to a liquid at constant temperature, latent heat is released. Only when the condensation process is finished, does the refrigerant temperature start to fall once more. This further cooling below the condensing temperature is called subcooling and most commonly occurs in the liquid line. The condensing process is illustrated in Figure 18. Figures 19 and 20 show how the temperatures change for refrigerant and for coolant.

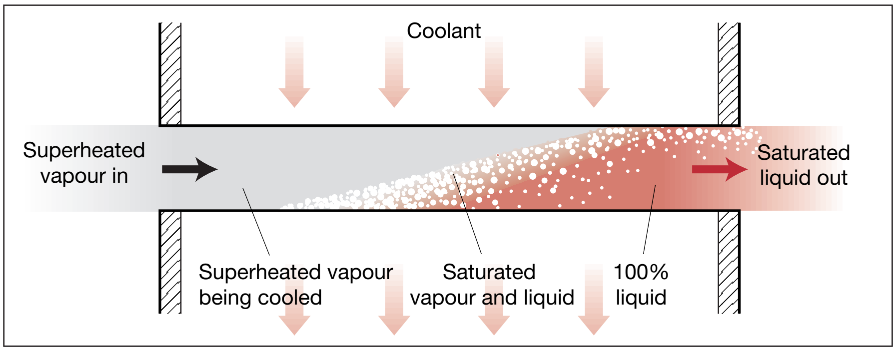


Figure 18 Refrigerant flow in a condenser tube (not to scale – diagrammatic only)

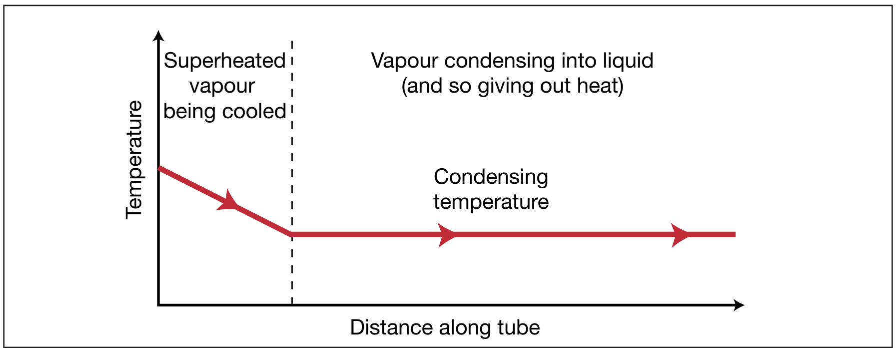


Figure 19 Temperature graph of the refrigerant as it flows along the condenser (shown for the case of a single substance, not a blend)

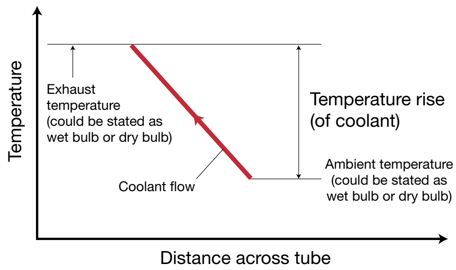


Figure 20 Temperature change for a single-phase coolant flowing across/ around the condenser tube (The coolant could be air, water or another fluid)

In the case of evaporative condensers, the cooling effect is enhanced by allowing water to evaporate in the air blown over the tubes. This cools the air to its weld bulb temperature. This would give a slighly different coolant temperature graph from that shown in Figure 20.

The Approach Temperature Difference (ATD)

In order to transfer heat from the refrigerant to the coolant, there must be a temperature difference between the two, and this is called the approach temperature difference (ATD), illustrated in Figure 21. This must be large enough to provide the heat flow needed to achieve the required system capacity. However, for maximum efficiency, the ATD should be minimised, as this will reduce the temperature lift of the system. A sensible balance between these two factors has to be made to ensure adequate capacity, but at reasonable running cost and environmental impact.

See Section 1.2 (key factors that affect efficiency and COSP)

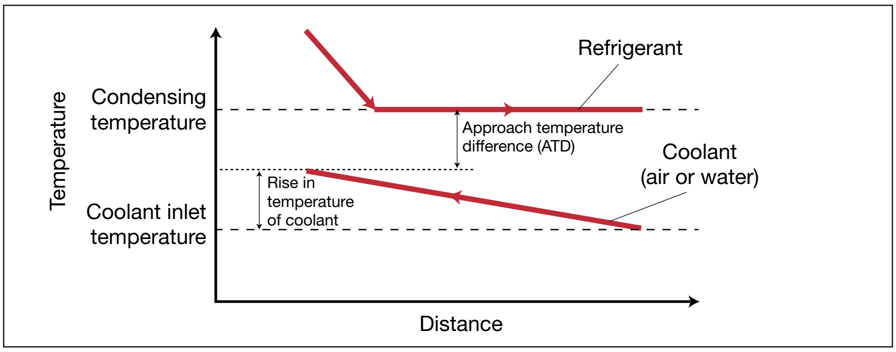
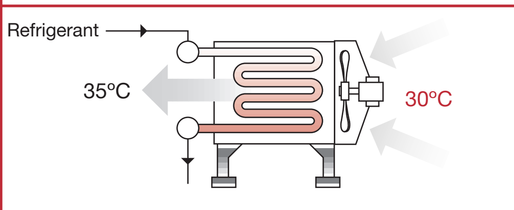
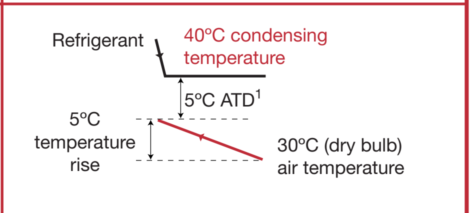
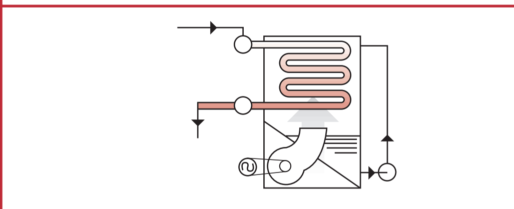
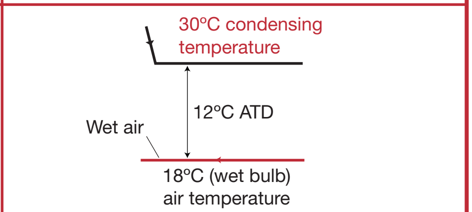
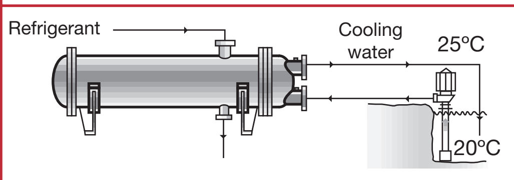
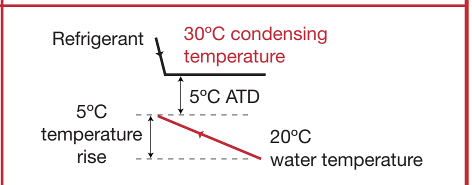
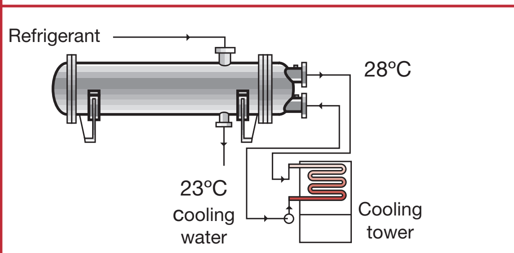
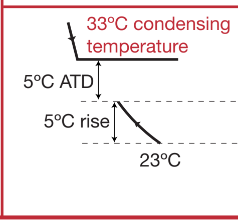
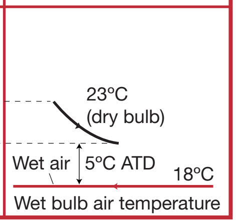


Figure 21 Diagram showing approach temperature difference between refrigerant and coolant in a condenser

The inlet temperature of the coolant is usually not controllable (e.g. ambient air temperature, or temperature of water available) but the coolant should be selected to have as low a temperature as possible. The lower the coolant temperature, for a given ATD, the more efficient the system will be. The coolant temperature naturally rises as it cools the refrigerant – the magnitude of this temperature rise depending on the flow rate and the type of coolant used. For maximum efficiency, this temperature rise should be kept low, as that means the condensing temperature can also be lower. However, the higher flow rates required would need larger fans and/or pumps, which also consume energy. As ever with refrigeration systems, a sensible balance (i.e. optimum design) must be found between conflicting requirements. Figure 22 shows some typical design values for ATD, coolant temperatures and resultant condensing temperatures for four common types of condenser.

CONDENSER TYPE	DIAGRAMMATIC ARRANGEMENT	TYPICAL CONDENSING TEMPERATURE
AIR-COOLED		
EVAPORATIVE		
SHELL AND TUBE WATER-COOLED (supplied from a river)[2]		
SHELL AND TUBE WATER-COOLED (supplied from a cooling tower)		Condenser:  Cooling tower: 

Notes:

[1] The ATD for air-cooled compressors is often as high as 15°C, but this is not strictly necessary with good design.

[2] Temperature of borehole water can be as low as 10°C. Condenser supplied thus would achieve condensing temperature of 10°C + 5°C rise + 5°C ATD = 20°C.

Figure 22 Four common condensing systems, and typical design temperature used, and their resultant condensing temperatures (See Figure 21 for an explanation of the temperature diagrams)

There are three types of condenser in widespread use:

- air-cooled (using ambient air);
- water-cooled (using mains, river or cooling tower water);
- evaporative-cooled (using ambient air and recirculated water).

The two latter types take advantage of the lower wet bulb ambient temperature and the greater heat transfer effect of water, and therefore operate with lower condensing temperatures. When comparing different condenser types, the power requirements of associated fans, pumps and heaters should be taken into account. In general, systems under 100 kW capacity use air-cooled condensers unless there is a space or noise restriction.

Air-cooled condensers

In an air-cooled condenser the refrigerant condenses inside finned tubes over which air is forced by fans.

If air-cooled condensers are being used in a corrosive atmosphere (for example, near the sea or in polluted air) the fins are made of copper, or the fin block is tinned or coated with PVC.

Air-cooled condensers are susceptible to blockage by airborne debris such as dust, feathers, packaging, and so on. They must be regularly cleaned to prevent a build-up of contamination, as this will reduce the air flow and hence increase the condensing pressure. Also, if the condenser is in a vulnerable position, the face of the fin block must be protected to prevent damage, but there must still be free circulation of air.

For smaller systems, the air-cooled condenser is built onto a base frame with the compressor and receiver, as shown in Figure 23. Packaged water chillers are also available up to very large sizes, where the whole assembly, including air-cooled condensers, are mounted on one base plate.

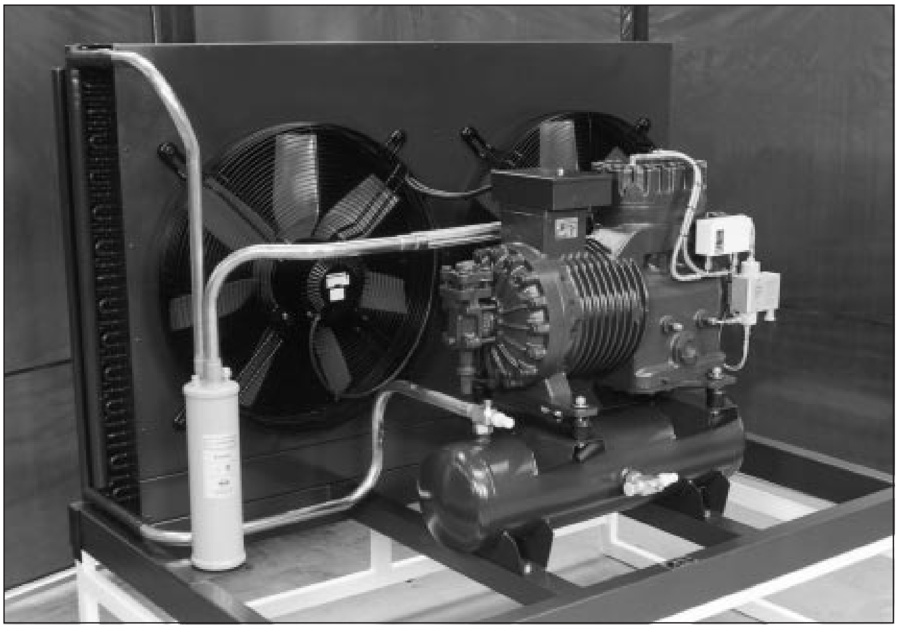


Figure 23 Air-cooled condensing unit

Water-cooled condensers

In a shell and tube water-cooled condenser, the refrigerant vapour is cooled then condensed in the shell of the unit, by cooling water flowing through the tubes (see Figure 24). Water-cooled condensers are commonly used in conjunction with water cooling towers or with free cooling water of suitable quality in certain circumstances where this is available.

Figure 24 Water-cooled condenser

Plate heat exchangers are also used as water-cooled condensers.

Condensers which use water from a borehole, sea or river operate with low condensing pressures, and are therefore the most efficient. When used with water from a cooling tower, the level of energy efficiency is comparable with that of an evaporative condenser, both taking advantage of the ambient wet bulb temperature as a means of cooling. The cooling water must be treated to prevent the formation of *Legionella* bacteria.

Evaporative condensers

The evaporative condenser utilises both ambient air and the evaporation of water to remove heat from the refrigerant vapour flowing inside the coils of the unit. Ambient air is blown up over the condenser into water sprayed down from a sparge system mounted above the condenser (see Figure 25).

Figure 25 Evaporative condenser

The water absorbs heat from the refrigerant and evaporates into steam at the prevailing wet bulb temperature. This steam is rapidly removed by the circulating air. This improves the cooling effect because the surface temperature of the condenser pipes approaches wet bulb temperature, increasing the efficiency of the unit. A continuous make-up of the circulated water is required to replenish that lost by evaporation.

The big advantage of evaporative condensers over shell and tube condensers and cooling towers is that the circulating water pump is much smaller. However, an evaporative condenser needs to be placed close to the compressor, to avoid long runs of refrigerant pipework.

Condenser efficiency issues

The three types of condenser most commonly used in refrigeration all have associated levels of energy consumption which must be taken into account:

- air-cooled – fan power;
- water-cooled – circulating pump power and, usually, cooling tower components;
- evaporative – fan and pump power.

The more surface area a condenser has, the closer the condensing temperature is to the temperature of the cooling medium, whether air or water. This lower condensing temperature results in lower energy consumption.

The heat transfer of all condenser types is reduced if they are dirty:

- air-cooled condenser fin blocks should be free of debris and in good condition;
- water-cooled condenser tubes should not be fouled, corroded or scaled-up (cooling water will usually need to be treated to avoid this).

Air or other non-condensables in the system will increase the condensing temperature which results in lower efficiency. Good installation procedures (i.e. evacuation) will prevent this happening. In large systems which work with a suction pressure below atmospheric pressure, air can be drawn into the system during operation. This should be removed automatically using a refrigerated air purger (this type prevents loss of refrigerant to atmosphere when the air is removed).

The condensing pressure should be allowed to float with ambient temperature to take advantage of the lower ambient temperatures overnight and during winter. This causes the pressure ratio to vary significantly, and can cause problems with some types of commonly used expansion valve. To avoid this, more sophisticated expansion devices should be used, such as electronic or balanced port types, or liquid pressure amplification should be considered (see Section 2.6).

2.4 Expansion devices

The purpose of the expansion device is to reduce the pressure of the liquid refrigerant after the condenser so that evaporation can take place. Some types of expansion valve also control the flow of liquid refrigerant into the evaporator in order to:

- vary system capacity to meet demand;
- prevent liquid refrigerant leaving the evaporator and causing damage to the compressor.

The correct selection and installation of an expansion device are very important. If it does not control correctly, the efficiency and reliability of a system will be reduced.

There are four types of expansion device widely used in commercial and industrial refrigeration:

- capillary tubes (small systems) and orifice plates;
- thermostatic, electronic or balanced port expansion valves;
- float valves (high and low side);
- hand expansion valve and level switch.

Capillary tubes and orifice plates

A capillary is simply a length of small bore-tube – its length and bore are selected to achieve the required pressure drop. It is normally used only on small factory-produced systems, e.g. display cabinets, bottle coolers, ice-making machines, etc. These types of system usually have constant loads, and any small variations result in a reduction of system efficiency.

As a capillary tube cannot control flow, the refrigerant charge in such systems is critical in order to avoid compressor damage and to achieve maximum efficiency. System cleanliness is also very important to avoid any blockage in the capillary tube.

Some large water chillers use an orifice plate in exactly the same way. The same disadvantages apply.

Thermostatic expansion valves

Thermostatic expansion valves are used on most commercial systems. A typical example is shown in Figure 26. The refrigerant pressure is dropped through an orifice, and the flow of refrigerant is regulated by a needle valve and diaphragm arrangement. The diaphragm is moved by pressure generated inside the controlling phial, which senses the temperature of the refrigerant leaving the evaporator. This should be approximately 5°C above the evaporating temperature to ensure there is no liquid refrigerant returning to the compressor.

This temperature difference (the superheat) is set by adjusting the pressure exerted by the spring. Correct setting is vital to the efficient and reliable operation of the system. If the load on the evaporator changes, the temperature of the refrigerant leaving the evaporator also changes. The controlling phial senses this and automatically adjusts the refrigerant flow to accommodate the load change.

A major disadvantage of thermostatic valves is that they cannot work as well if the pressure difference across them reduces significantly, e.g. when the condensing pressure floats down with falling ambient temperature. To cope with such conditions, balanced port and electronic expansion valves can be used.

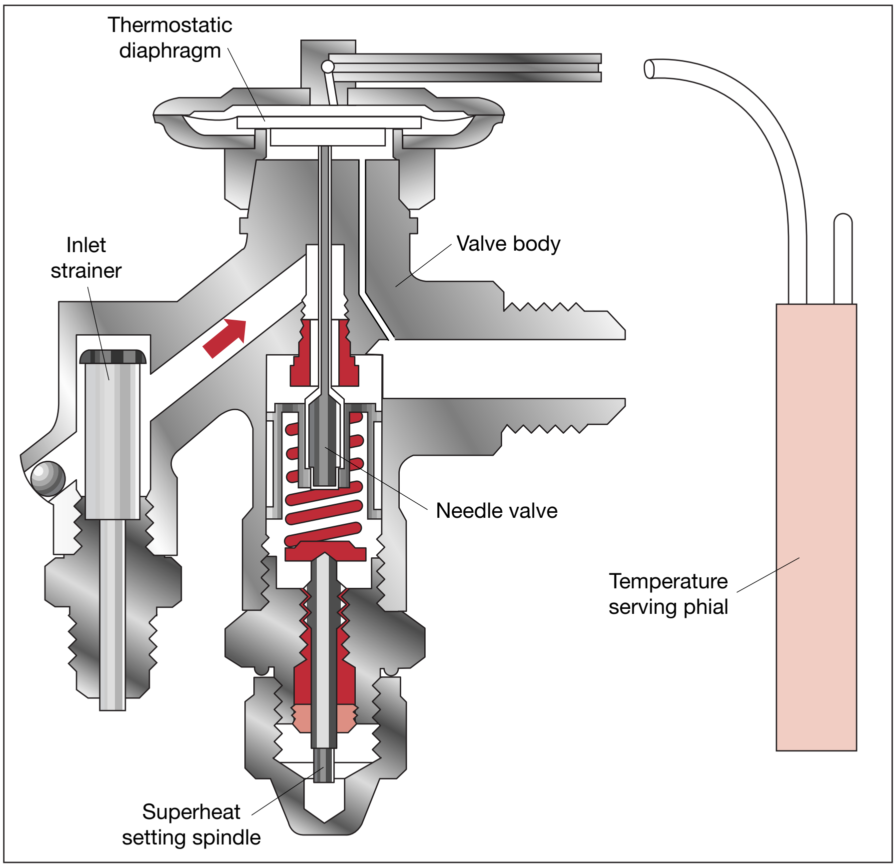


Figure 26 Diagram of a thermostatic expansion valve

Balanced port valves

Balanced port valves are very similar in design and operation to the conventional thermostatic valve, apart from a special internal balanced port design. This allows the valve to control the flow of refrigerant accurately over a wider range of pressures. These valves cost approximately 20% more than a conventional valve, and are available only in a limited range of sizes.

Electronic expansion valves

Electronic valves work in a similar way to thermostatic valves, except that the temperature is sensed electronically and this signal is used to open and close the orifice by applying heat to a fluid (similar to a thermostatic expansion valve) or by driving a small electric actuator. This form of control is much more precise and the valve can, therefore, operate with a wider range of condensing and evaporating pressures. A further advantage is that they can be easily integrated into an electronic or microprocessor control system.

Electronic valves are more expensive than other types and the payback may only be attractive on larger systems. Good Practice Case Study 302 *Improving refrigeration performance using electronic expansion valves* explains the benefits, and demonstrated that using this type of valve with direct expansion evaporators in a medium-sized cold store gave a payback in 1.4 years.

Electronic expansion valves see GPCS 302

Float valves

There are two main types of float valve used in refrigeration:

- the high-side or high-pressure float, operating at the high-side pressure;
- the low-pressure float which operates at the low-side pressure.

The high-pressure float usually has the expansion valve integral within the float chamber, the low-pressure float can have either an integral expansion valve or one remotely mounted in the liquid line controlled via a pilot line.

High-pressure (HP) float valve

With this type of valve fitted in the liquid line directly from the condenser, or from the receiver itself, the refrigerant charge is minimised because the receiver can operate empty. This valve is only suitable for systems incorporating a single evaporator.

Extreme care is required when charging a system fitted with this type of valve as all liquid refrigerant entering the valve is passed to the low side of the system. The system is said to have a 'critical charge' and to ensure safe operation (avoiding over-charging which results in 'liquid carry-over' to compressors) a liquid level gauge must be fitted to the evaporator or the vessel from which the evaporator is fed.

Low-pressure (LP) float valve

This valve controls the flow of liquid refrigerant to the 'low side' of the plant by monitoring the liquid level in the evaporator (or in the vessel from which the evaporator is fed). It varies the degree of opening of an integral expansion valve, or on large systems varies the pressure in a pilot line to modulate the opening of an expansion valve in the liquid line.

With this type of valve, a level of liquid must be maintained in the receiver under all levels of load. A level gauge is necessary to enable the liquid level in the receiver to be monitored.

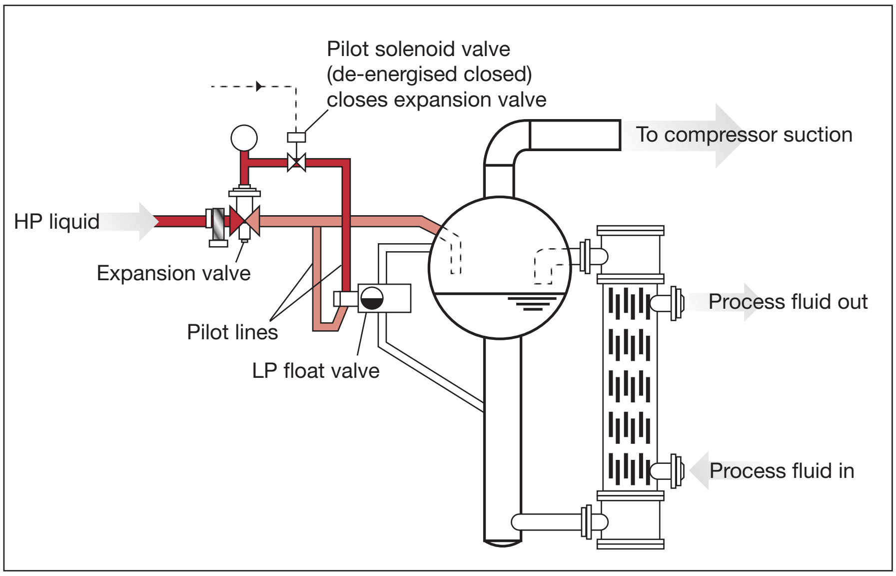


Figure 27 Diagram showing a low-pressure float valve usage

Manually adjusted expansion valve and level switch

An alternative method of feeding flooded evaporators (to the modulating type of expansion valve) is that of a float level switch. This opens and closes a solenoid valve positioned in the liquid line immediately upstream of a manually adjusted expansion valve.

This arrangement can be used for both HP and LP float-type systems.

With this arrangement, the manually adjusted expansion valve is set at a degree of opening that ensures the required rate of feed of liquid refrigerant is maintained at maximum load with minimum head pressure. At all other conditions, the period of time that the solenoid valve is open is reduced.

Expansion devices efficiency issues

Where capillary tubes or orifice plates are used, the refrigerant quantity is critical to capacity and efficiency. If a capillary tube is damaged or partially blocked it will not control the system correctly and the efficiency will reduce.

With thermostatic expansion valves the superheat setting has a significant effect on efficiency and reliability:

- if the superheat is too low, liquid refrigerant may return to the compressor, causing damage or failure;
- if the superheat is too high (usually above 5K), capacity and efficiency are unnecessarily reduced.

Thermostatic expansion valves do not control well over widely varying pressure differences so, to take advantage of floating head pressure, balanced port or electronic valves should be used.

The high pressure float has one advantage over all the other types of expansion device because it is fitted with a vent tube so that when the plant stops, the pressure differential across the valve equalises. Thus, on start-up, the compressor drive motor absorbs less power than during a normal start-up.

2.5 Refrigerants

All substances that exist in liquid and vapour states absorb heat during evaporation and could therefore be used as refrigerants. Water, for instance, could even be used, but its boiling point is too high to be of practical use. A refrigerant should evaporate at the required cooling temperature at a reasonable pressure, and must be able to be condensed by a readily available cooling medium (usually ambient air) at a practical pressure.

Refrigerants used in refrigeration and air conditioning are usually one of:

- CFCs – chlorofluorocarbons;
- HCFCs – hydrochlorofluorocarbons;
- HFCs – hydrofluorocarbons;
- HCs – hydrocarbons;
- NH_3 – ammonia.

CFCs deplete stratospheric ozone and, following the Montreal Protocol, are no longer produced. They were very widely used in the past, and are therefore still in older systems. HCFCs also deplete ozone, but to a lesser extent. They will be phased out of production in Europe in 2015 (*Note – negotiations underway at time of print may alter this schedule. Refer to the British Refrigeration Association, Appendix B*). Their use in some (larger) new systems is controlled under European Union regulations. HFCs have been developed during the 1990s to replace CFCs and HCFCs. HCs are also being used as replacements.

Refrigeration plant contributes to global warming indirectly due to the energy it consumes, as power stations emit carbon dioxide when they generate electricity; efficient plant will use less electricity and so have less indirect impact. In addition, many refrigerants are powerful greenhouse gases which contribute directly to global warming if they leak, and certain refrigerants also damage the ozone layer; good design and installation will minimise leakage.

The total of a refrigeration system's direct and indirect global warming impact is called its Total Equivalent Warming Impact (TEWI) value. The British Refrigeration Association has published guidelines to help calculate this (see page 57).

A summary of the characteristics of these refrigerant groups is shown in the table overleaf.

Type	**Examples**	**ODP ***	**GWP ****	**Uses**	**Other issues**
CFC	R12 R502 R11	High	High	Widely used in most applications until 1990.	Now phased out of production.
HCFC	R22 R409A R411B	Low	High	Widely used in many applications. Not recommended for use after 1999.	To be phased out of production in 2015. Their use is also regulated increasingly strictly.
NH_3 Ammonia	R717	Zero	Very low	Used in industrial systems since the birth of refrigeration.	Toxic and flammable, reacts with copper.
HFC	R134a R404A R407C R410C R507	Zero	High	Started to be used in place of CFCs from about 1990.	Different compressor oil needed, performance of some HFCs not as good as CFCs. Some reliability problems.
HC e.g. propane, iso-butane	R600a R290 Care 30 Care 50 R1270	Zero	Very low	R290 used in some industrial systems for decades. R600a now used in domestic systems. Care 30 and Care 50 now used in some commercial applications.	Flammable, but are very good refrigerants with few changes needed to a CFC/HCFC system.
CO_2 Carbon dioxide		Zero	Very low	Widely used before the 1950s, but superseded by halocarbons. Now being 'rediscovered' as a primary and secondary refrigerant.	Not yet in widespread commercial use as a primary refrigerant, but an interesting prospect. (High operating pressures require special materials and construction.)

* *ODP = ozone depletion potential* ** *GWP = global warming potential*

Many of the new refrigerants are blends of different substances which fall into two categories:

- those with a low ozone depleting potential (ODP) which are used as transitional substances, these are usually based on the HCFC R22 (e.g. R409A, R411B);
- those with zero ODP which have a longer term future, these are usually based on HFCs (e.g. R404A, R407C), or HCs (e.g. Care 30, Care 50).

The transitional substances are primarily used to convert existing systems – **they should not be specified for new equipment.** Because they include HCFC R22 they can operate with the existing (mineral) oil in the system and the conversion procedure is therefore usually fairly simple – a 'drop-in' procedure.

The blends based on HCFCs or HCs can be used to replace the HCFC or CFC refrigerant in existing systems without changing the oil. Blends based on HFCs are usually only used in new systems because otherwise an oil change would be needed.

The new blends described above are mostly blends of two or three substances and are usually given the number R4XX, e.g. R404A, R407C.

Blend issues: Zeotropic blends

Some blends behave differently in a system to a single substance like R22 or R134a. At a constant pressure, a pure refrigerant will have a single evaporating/condensing temperature, however, some blends evaporate and condense across a small temperature range. Such blends are said to have 'temperature glide', and are called zeotropic blends. For zeotropic blends:

- when the refrigerant is a saturated liquid (e.g. about to start evaporating) it is at the 'bubble temperature';
- when the refrigerant is a saturated vapour (e.g. about to start condensing) it is at the 'dew temperature'.

The difference between bubble temperature and dew temperature is the temperature glide, which varies depending on the refrigerant, but is usually between 1K and 8K.

This means that the evaporating temperature increases (from the bubble to the dew temperature) as the liquid boils; conversely, the condensing temperature decreases (from the dew to the bubble temperature) as vapour condenses. The practical effects of this are:

- increased capacity where the refrigerant and air/water/secondary refrigerant flows are in counter-flow;
- uneven ice build-up may occur (for example, affecting defrosting);
- blends must be removed from the cylinder as a liquid to retain the correct blend composition.

It is wise to check with the manufacturers of the refrigerant before using a zeotropic blend in a flooded evaporator system as it may affect the system's performance.

Blend issues: Azeotropic blends

It is also possible to have a blend for which there is no temperature glide (i.e. the bubble and dew temperatures are the same). These are called azeotropic blends, and include R502 and R507. They behave like single substances.

Hydrocarbon (HC) refrigerant issues

The HC refrigerants are flammable. This affects where they can be used safely, and how systems are designed and installed. However, they can and have been safely and successfully applied in a wide range of refrigeration systems, and their use increasing because of their good efficiencies.

Ammonia issues

The most commonly used refrigerant in flooded-type industrial refrigeration systems is anhydrous ammonia (chemical symbol NH_3, refrigerant number R717). Anhydrous ammonia has a high latent heat resulting in a low mass flow of refrigerant around the circuit and, therefore, reduced energy consumption.

The density of liquid ammonia is less than that of compressor lubricating oil. Thus oil removal is simply a matter of draining from low points of the system (for safety, on the low-pressure side of the system – and into an oil collection vessel). Ammonia vapour is approximately two-thirds the density of air and thus air is easily purged from the highest point on the condenser when the refrigeration plant is stopped or by automatic purging equipment. As both these contaminants can drastically affect the energy efficiency of an ammonia system, their removal is very important. Ammonia has good heat transfer properties in both the liquid and vapour phase.

Ammonia is toxic at high concentrations. COSHH occupational exposure limits control exposure to ammonia at 25 ppm, at which point the smell is quite obvious. Concentrations of vapour up to 250 ppm can be tolerated by most people, causing only irritation and discomfort with no cumulative effect. At 3,500 ppm, ammonia is quite quickly lethal (30 minutes). A 16 – 27% (by vol.) ammonia air mixture can, with difficulty, be ignited. Ammonia also attacks copper, zinc, tin, cadmium and their alloys.

Standards

The revised British Standard 4434:1995 *Safety and environmental aspects in the design, construction and installation of refrigerating appliances and systems*, which covers safety in all types of refrigeration system, gives guidelines on how all refrigerants (including HCs and ammonia) should be applied safely. This Standard will be superseded by the European Standard EN 378.

Secondary refrigerants

See indirect systems page 39

Systems using secondary refrigerants, known as indirect systems, are described in Section 3.4. In principle, this just means that the refrigeration plant operating on its own (primary) refrigerant is used to cool an intermediate (secondary) refrigerant which is pumped to the point where cooling is required. Secondary refrigerants are used in many applications, often to reduce the amount of toxic, flammable or environmentally-damaging primary refrigerant used, or to prevent product contamination by the primary refrigerant in the event of a leak. The use of indirect systems is increasing to enable flammable/toxic refrigerants (which are usually more energy efficient) to be safely used in more applications.

Most secondary refrigerants absorb sensible heat, i.e. change temperature, as they cool the product. Some, however, absorb latent heat by changing from liquid to gas, or solid to liquid, and so have a higher capacity per unit mass flow. The temperature of the secondary refrigerant may, therefore, not change and so the temperature difference is maintained for good heat flow. Secondary refrigerants using latent heat include carbon dioxide and slurry-ice.

Refrigerant efficiency issues

The type of refrigerant can affect the efficiency of a system by up to 10%.

The relative performance and efficiency of a refrigerant is affected by the type of compressor and the operating conditions.

Zeotropic blends can give advantages in capacity and efficiency when used in the correct way (i.e. advantage is taken of temperature glide in the evaporator).

See GPG 178 *Cutting the cost of refrigerant leakage*

The amount of charge is important – too much and especially too little refrigerant can reduce efficiency.

It is important that systems do not leak refrigerant – insufficient refrigerant reduces evaporator wetted surface area and results in increased superheat. This reduces the suction pressure and increases the temperature lift, thus reducing efficiency. See Good Practice Guide 178 *Cutting the cost of refrigerant leakage*.

If refrigerant is contaminated, e.g. with air, the efficiency of the system is reduced.

2.6 Other system components and features

There are other important components and features used in some or all systems to improve operation or performance. These are described below.

System control

Systems are usually controlled either by a thermostat in the cooled space or secondary refrigerant, or by the suction pressure. It is important that these controls do not allow the system to operate at a lower evaporating temperature than necessary (thus increasing the temperature lift and the duration of operation).

There will also be safety devices on most systems. These can include:

- a high pressure switch connected to the compressor discharge which will switch off the system if the high pressure exceeds the setting (i.e. a safe level);
- a pressure relief device on the receiver which will open and allow the refrigerant to escape if the pressure exceeds the setting (i.e. before it builds up to a dangerously high level).

Some systems may have a control (often another high pressure switch) to regulate the condensing pressure and maintain it at a high level regardless of ambient temperature. This forces the system to always operate at a high temperature lift, thus reducing system efficiency.

A low-pressure switch is used on many systems to control the pump-down system and shut off the compressor when the application is down to temperature. A solenoid valve in the liquid line closes when the system has achieved the desired temperature. The system carries on running until the suction pressure reaches the setting of the low-pressure switch – the compressor then stops with the liquid refrigerant safely contained in the high side of the system. In this way there is no possibility of liquid refrigerant flooding into the compressor and causing damage.

Insulation

Insulation is important in reducing heat loads on a refrigeration system. In particular it will be used to:

- reduce heat gains into cooled spaces such as cold stores and cabinets;
- reduce the heat gain into the suction vapour between the evaporator and the compressor (process 2 → 3 of Figures 3 and 4).

More guidance on the specification of insulation is given in Fuel Efficiency Booklets 8 and 19

Heat recovery

The condensing refrigerant in a refrigeration system is warmer than ambient temperature. The amount of heat rejected in the condenser is the cooling effect plus most of the compressor input power. Heat can be recovered from:

- The discharge vapour, which can be as hot as 150°C. The heat is removed in a de-superheating vessel between the compressor and condenser. The amount of heat available is, however, relatively small.
- The condenser, which is normally 10 to 30°C above ambient temperature.
- The oil used on oil-cooled compressors, which can be between 60 and 80°C.

It is essential that the effect of heat recovery on the performance of the refrigeration system is carefully analysed. In many cases, recovering useful heat from the condenser forces the system to operate less efficiently (i.e. at a higher condensing temperature), and the savings in heating costs are usually less than the added refrigeration costs.

See GPG 141 *Waste heat recovery in the process industries*

A ***de-superheater*** recovers high temperature heat from the discharge vapour leaving the compressor. The discharge temperature depends on the operating conditions of the system and the refrigerant. R22 and ammonia operate with significantly higher discharge temperatures than most other refrigerants.

In a well designed refrigeration system the condensing temperature should be as low as possible. Any heat recovered from the ***condenser*** will be at a very low temperature and is very rarely useful.

In oil-flooded screw compressors much of the motor heat is dissipated into the ***lubricating oil***. The oil usually enters the compressor at about 40°C and leaves it at 60 to 80°C. For an R22 system, about 38% of the motor power would be absorbed by the oil and consequently be available for recovery. For ammonia systems this figure increases to about 60%.

Liquid receiver

A liquid receiver is used on all systems, except those with a capillary tube expansion device, to:

- hold a buffer of refrigerant to ensure there is always liquid available if the load on the evaporator changes;
- hold all the refrigerant charge safely during a pump-down operation.

The receiver is a pressure vessel and must usually be protected by pressure relief devices. For more information see the British Standard 4434:1995 *Safety and environmental aspects in the design, construction and installation of refrigerating appliances and systems*, the Pressure Equipment Directive and the Pressure System and Transportable Equipment Regulations.

Suction/liquid heat exchanger

The cooling effect of an evaporator is proportional to the length of the line between points 1 and 2 in the pressure-enthalpy diagram of Figure 3. Cooling capacity is increased by lowering the temperature of the liquid at the inlet to the expansion device (i.e. increasing the liquid subcooling).

The temperature of the refrigerant leaving the evaporator is lower than that of the liquid entering the expansion device. Therefore, it is possible to reduce the liquid temperature by using a heat exchanger between these two points (between points 2 and 7 on Figures 3 and 4).

There will be a corresponding increase in the suction vapour temperature entering the compressor. This will reduce the compressor's capacity as the vapour will be less dense and therefore less refrigerant will be pumped. In general, the gain outweighs the loss at evaporating temperatures above -15°C.

Care must also be taken when using these heat exchangers on systems with refrigerants R22 and R717 (ammonia), where the increased suction temperature could result in an excessive compressor discharge temperature.

Oil separation systems

Refrigeration compressors pump a small amount of oil with the refrigerant. The installation should be designed to ensure that this oil circulates around the system and returns to the compressor. Oil logging in components such as evaporators can significantly reduce their efficiency and a shortage of oil in a compressor will decrease its reliability and eventually result in a mechanical failure.

Some refrigerants do not carry oil around the system reliably, so it is necessary when using these refrigerants (or when there are significant variations in the system load) to install an oil separator in the discharge line just after the compressor. The oil separator will remove the majority of the oil from the discharge vapour and return it to the compressor's crankcase.

Where compressors have been installed in parallel (e.g. to meet a large load) an oil management system is required to ensure that oil is returned only to the compressors that need it – failures and loss of efficiency can occur if a compressor's crankcase is overfilled with oil as well as if there is too little. Each compressor is fitted with a valve which senses the crankcase oil level. As the level drops so the valve opens, allowing a flow of oil from the reservoir to enter the crankcase to maintain the optimum level.

Filter drier

It is critical to the efficient and reliable operation of any refrigeration system that the refrigerant is kept free from moisture and particles. Moisture can freeze at the expansion device, restricting or completely blocking the flow of refrigerant. Small particles can have a similar effect and can damage the internal working parts of valves and compressors. To prevent this happening, a filter drier is installed in the liquid line. These are fitted with a fine mesh filter and are filled with a desiccant to absorb moisture.

Sight glass

A sight glass is fitted in the liquid line of all but small commercial systems. It gives a visual indication that the refrigerant in this line is liquid. It is used:

- to gauge the correct charge during installation;
- to check that the system is fully charged during operation and maintenance (although vapour bubbles in the sight glass also occur if the filter drier in the liquid line is blocked).

A shortage of refrigerant, e.g. due to a leak, significantly reduces the system efficiency. More information is given in Good Practice Guide 178. Most sight glasses also incorporate a visual indicator which responds to the dryness of the refrigerant. Any moisture present will change the colour of the indicator.

Refrigerant leakage
see GPG 178

Pipework

Copper or steel pipework is used to join the system components to make a complete circuit. The pipework is designed and installed to:

- minimise pressure drops, thus keeping the compressor compression ratio as low as possible to maintain efficiency;
- allow oil to return to the compressor by ensuring the refrigerant's velocity is sufficiently high.

Both the pipe sizing and its routing will have an impact on these requirements.

Liquid pressure amplifier (liquid line pump)

Liquid pressure amplification (LPA) is used to increase effectively the level of subcooling at the expansion valve and reduce the amount of work needed by the compressor. This is achieved by using a liquid pump between the receiver outlet and the expansion valve. The pump raises the pressure of the liquid into the expansion valve, so the valve will control well even when the head pressure floats down with falling ambient temperature. Significant energy savings and improvements in reliability have been reported by users of LPA systems.

3

SYSTEMS AND APPLICATIONS

Refrigeration is very widely used in most industry sectors – many companies rely on refrigeration for producing and/or storing products. There are few modern industrial processes that do not, at some stage, require the extraction of heat to effect a change in temperature and/or state. Most refrigeration systems are used in the following industry sectors:

- food and drink retailing;
- chemicals manufacture;
- refrigerated transport;
- food and drink processing;
- cold storage.

Air conditioning and domestic refrigeration are not covered by this Guide.

Most commercial and industrial refrigeration systems fit into one of eight categories and they are described in this Section.

Efficiency issues: for ALL systems the following golden rules apply:

- ✓ The load should only be that which requires mechanical cooling (as opposed to that which can be pre-cooled using cooling fliuds at ambient temperatures, e.g. ambient air). The load should be as low as possible.
- ✓ The condensers and evaporators should be sized to maintain the lowest practical condensing temperature and the highest effective evaporating temperature.
- ✓ Head pressure control should be avoided or minimised.
- ✓ The compressor/refrigerant combination should be the most efficient for the application.
- ✓ The suction line should be insulated.
- ✓ The system should contain the correct type and amount of refrigerant and be leak-free.
- ✓ The condenser and evaporator should be cleaned regularly.
- ✓ The evaporator should be defrosted as necessary.

Additional efficiency issues associated with each system category are included below.

3.1 Commercial integral appliances

Commercial appliances are used in retail and catering outlets and in licensed premises for the storage and/or display of frozen and chilled food and drinks. Such appliances include:

See GPG 277 *Saving money with refrigerated appliances*

- display cabinets for chilled and frozen food;
- ice cream conservators;
- fridges and freezers for commercial kitchens;
- bottled and canned drink chillers;
- ice-makers;
- beer coolers.

They are self-contained, i.e. the refrigeration system is integral to the cabinet, and they are always produced in a factory. (Some display cabinets have remote refrigeration systems – these are covered in Section 3.6 on supermarket central plant systems.)

Component	Type
Compressor	Hermetic reciprocating or scroll, up to 4 kW nominal motor size.
Condenser	Air-cooled, usually with a fan. Ice cream conservators have a skin condenser (i.e. copper coil wound around the outer cabinet skin) as well as a dynamic condenser.
Receiver	Fitted to appliances using a thermostatic expansion valve.
Expansion device	Capillary tube or thermostatic expansion valve.
Evaporator	Fin and tube with fan in most cases. Defrost, where necessary, is usually by heaters. Ice cream conservators have a copper coil or Bundy tubing wrapped around the inner skin of the cabinet and rely on manual defrosting.
Refrigerant	R134a, R404A, hydrocarbons.
Additional components	Capillary tube systems usually include a simple suction to liquid line heat exchanger.

Specific efficiency issues for commercial integral appliances

If you are buying or using such appliances, refer to GPG 277 *Saving money with refrigerated appliances.*

Buying integral appliances see GPG 277

- **Product should not be loaded beyond the load line, and should not be loaded at a temperature above the storage temperature.**
- **Thermostats should not be set lower than necessary.**
- **The condenser air flow should not be restricted – this usually means the appliance should be sited a minimum distance from walls and other obstructions.**
- **The appliance should not be located in direct sunlight, or near heaters.**
- **The appliance should be regularly cleaned and debris removed from air flow inlets/outlets.**
- **On open fronted appliances such as retail display cabinets, night blinds or PVC strip curtains should be used to reduce heat gain.** (Note: The control circuits must be designed for use with night blinds otherwise there is a serious risk of plant short cycling due to the dramatic reduction of load when the night blind is in use.)

Night blinds and PVC strip curtains see GPCS 223 and GPCS 350

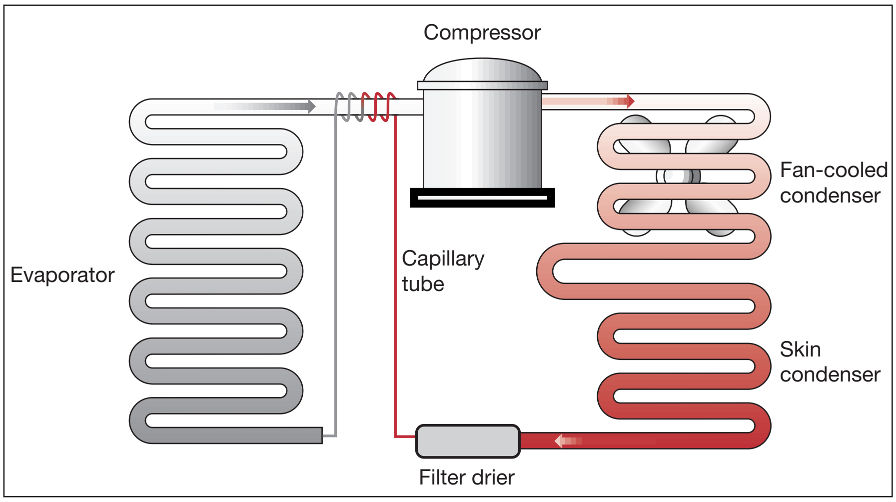


Figure 28 Schematic diagram of a typical ice cream conservator-type system

Figure 29 Integral retail display cabinet

3.2 Cold stores

Cold stores are used in many shops and most supermarkets and in many catering and retail premises for the storage of chilled and frozen food, and chilled beer and other drinks. On a larger scale, there are public and distribution cold stores. Most are designed to suit the particular application and are assembled on-site. Some modular cold store packages are available.

Cold store systems see GPCS 230

Component	Type
Compressor	Most common, semi-hermetic reciprocating compressors. Also used, hermetic reciprocating and scroll, and semi-hermetic and open screw. Size range: all.
Condenser	Usually air-cooled with a fan, occasionally water-cooled using cooling tower water.
Receiver	Fitted on all systems.
Expansion device	Thermostatic expansion valves are most commonly used, occasionally balanced port or electronic types are used. Very large systems will use pumped refrigerant and low - pressure float valves.
Evaporator	Fin and tube with up to four fans. Defrost, where necessary, is usually by electric heater, but warm/cool gas is also used. Higher temperature applications, e.g. beer cellars, use natural defrosting.
Refrigerant	R134a, R404A, R407C. Ammonia for large stores.
Additional components	In larger stores, several evaporators will be used with either a central plant system or separate systems.

The diagram in Figure 30 (from GPCS 230) shows a typical large cold store system.

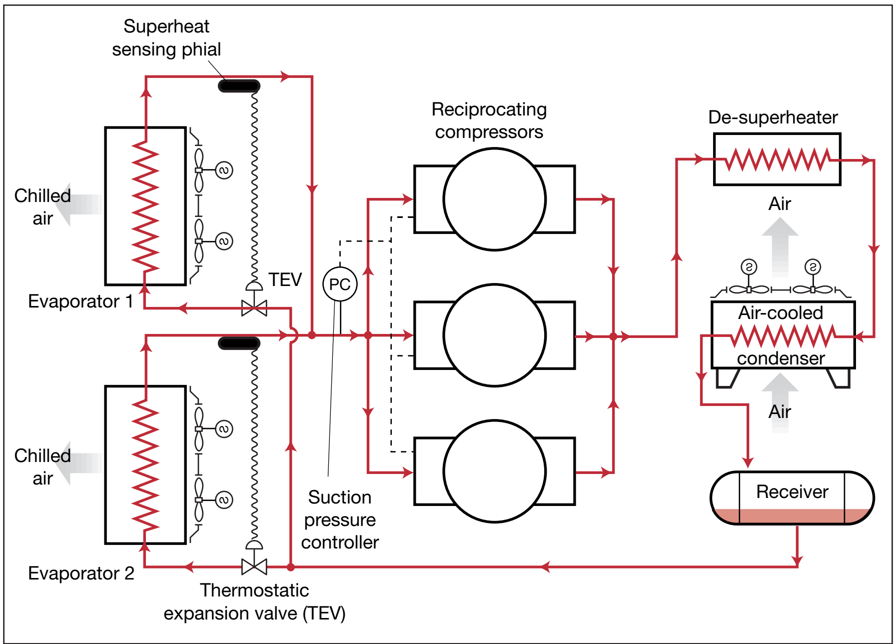


Figure 30 Schematic diagram of an integrated refrigeration system

Specific efficiency issues for cold stores

- **Ensure product is loaded so that it does not impede the air flow to/from the evaporators.**
- **Ensure product is not warmer than the store temperature when it is loaded.**
- **The thermostat should not be set lower than necessary.**
- **Keep doors closed except when necessary.**
- **Use door strips or an air lock to minimise heat gain when doors are open.**
- **Maintain door seals in good condition.**
- **On large, low-temperature stores use of an air lock significantly reduces the latent load.**

3.3 Packaged water chillers

The two main applications of water chilling are:

- chilling water to around 5°C for use in fan coil units applied to space cooling, as shown in Figure 31, or for process cooling;
- chilling water to around 0.5°C for use, for example, in the final stage of milk cooling subsequent to pasteurisation.

Loads of all sizes can be handled by packaged water chillers, for temperatures down to about 5°C. For lower temperatures and special applications, bespoke chillers will be designed (see Section 3.4).

Packaged water chillers are supplied as complete units, usually mounted on a single base frame.

Component	**Type**
Compressor	All types. All sizes.
Condenser	Air-cooled or water-cooled.
Receiver	Fitted.
Expansion device	Thermostatic expansion valve (smaller sizes), orifice plates (older designs for large sizes), or HP and LP float.
Evaporator	Shell and tube.
Refrigerant	R134a, R22, R407C.
Additional components	Chilled water tank and pumps.

Specific efficiency issues for packaged water chillers

- **Compressors should be sized and controlled to minimise part-load operation.**
- **Water pump flow rate should be variable to match the load closely.**

3.4 Indirect systems (including bespoke water chillers)

The use of indirect systems is increasing as some users are moving away from traditional central plant systems. Indirect systems use a primary system to cool a secondary fluid which cools the display cases, cold stores etc. The advantages of such a system are:

- The primary refrigerant charge is significantly smaller, thus reducing the potential for leakage. Refrigerant is restricted to the plant room area, therefore leak detection is simplified and repairs more easily carried out.
- The primary refrigerant no longer has to travel through very long pipe runs, so the pressure drops are significantly lower.
- Room and case coolers are more efficient since 100% of the cooler tubing is in contact with the cooling medium. This increase in cooler efficiency negates the need to evaporate at a lower temperature than a conventional DX system.
- The more environmentally benign refrigerants such as ammonia and hydrocarbons can be safely used as they will normally be contained in plant on the roof and will not circulate in public areas.

A disadvantage of this system is that there is an additional heat exchange needed which results in some heat loss. This can cause a higher temperature lift compared to direct systems, although this disadvantage can be outweighed by the reduction in pressure drop.

Packaged water chillers can be used for secondary refrigerants, but they become less appropriate as the temperature falls below 0°C. Generally, bespoke chillers are more appropriate for these duties.

Figure 31 shows a typical indirect commercial system.

Figure 31 A roof-top hydrocarbon chiller

This chiller operates with a secondary refrigerant distributing to the display cases on the shop floor below
Courtesy of Tesco

Component	Type
Compressor	All types. All sizes.
Condenser	Evaporative or air-cooled.
Receiver	Fitted.
Expansion device	Direct expansion or low-pressure float valve.
Evaporator	Shell and tube, plate or Baudelot (water only).
Refrigerant	R22, R407C, R410A, ammonia, hydrocarbons.
Additional components	Chilled water tank and pumps.

Specific efficiency issues for indirect systems

- **Compressors should be sized and controlled to minimise part-load operation.**
- **High efficiency motors should be used on open drive compressors.**
- **Select a secondary refrigerant which absorbs as much heat as possible for a low flow rate.**
- **Reduce the mass flow of secondary refrigerant by selecting one which absorbs latent heat.**
- **Select a secondary refrigerant which has a suitable viscosity over the operating range (to reduce pump power).**
- **Size the circulating pump carefully to avoid throttling an oversized pump.**
- **Utilise variable speed drive/multiple pumps to maintain energy efficiency over a range of secondary refrigerant flow rates.**
- **If possible, the secondary refrigerant supply to the consumers should be varied. Where water is the secondary refrigerant, this may require a separate, constant-flow loop to prevent freezing in the evaporators.**

3.5 Milk tanks

Milk tanks are used on all dairy farms to cool the milk immediately after milking. They usually use a condensing unit with a specially designed evaporator/milk tank. These two main components are assembled on-site.

Component	Type
Compressor	Most common, hermetic reciprocating or scroll compressors. Also used, semi-hermetic reciprocating compressors. Size range 1 to 7 kW.
Condenser	Air-cooled with fan.
Receiver	Fitted on all systems.
Expansion device	Thermostatic expansion valve.
Evaporator	Most common, thermoplate with channels formed by welding two sheets together – the evaporating refrigerant flows through the channels formed. The evaporator is the bottom section of the milk tank. Sometimes used, ice blank tank where evaporating refrigerant flows through copper tubes immersed in a water/ice tank.
Refrigerant	R134a, R22, R407C.
Additional components	Heat recovery from the discharge vapour is fairly common.

Figure 32 Refrigerated milk tank

Specific efficiency issues for milk tanks

- **Ensure the condensing unit is sited in an area where there is plenty of air flow and out of direct sunlight.**
- **If heat recovery is used, ensure it does not force the refrigeration system to work less efficiently than it should.**

3.6 Supermarket direct expansion central plant systems

Most supermarkets use a central plant system to provide liquid refrigerant for display cases on the shop floor and for cold stores and preparation areas. The load is large, so two or more compressors are fitted in parallel. They discharge into a common header and the vapour is taken to a common condenser and receiver. The liquid is then distributed to a header with connections to each evaporator.

Usually the high temperature (chilled food) and low temperature (frozen food) loads are handled with two separate packs. The ice cream is also often separate.

Component	Type
Compressor	Semi-hermetic reciprocating, hermetic scroll or semi-hermetic screw. Size range 5 to 50 kW nominal motor power.
Condenser	Air-cooled remote condenser.
Receiver	Always fitted.
Expansion device	Most common, thermostatic expansion valve. Sometimes used, electronic expansion valve.
Evaporator	Fin and tube evaporators in display cases, cold stores and preparation areas. Where defrosting is necessary, it is by electric heater or cool/warm vapour.
Refrigerant	R22, R134a, R404A.
Additional components	An oil management system will be necessary.

Figure 33 shows a typical central plant for frozen food.

Figure 33 Central plant compressor pack for frozen food display

Specific efficiency issues for supermarket direct expansion central plant systems

- **Ensure the compressors are controlled to minimise operation on part-load.**
- **Ensure the suction pressure control is not set lower than necessary.**
- **These systems are prone to leakage because of the long pipe lengths and high number of joints – make sure they are leak tested regularly and thoroughly.**

3.7 Blast freezers (including freezing tunnel or spiral freezers)

Blast freezing is carried out with large volumetric flows of air chilled to temperatures of around -30°C. To achieve this, an evaporating temperature of the order of -35°C is required, thus two-stage compound cycles (see 3.8) are usually used, as shown in Figure 37.

The freezing can be a batch process where a quantity of product is loaded into the freezer and the 'batch' is frozen, usually overnight, for removal to store the following morning. Freezing can also be a continuous process using a conveyor belt system arranged along a tunnel, or in a more compact box enclosing a spiral conveyor system (spiral freezer). 'Hardening tunnels' used in ice cream manufacture are also a form of blast freezer.

Component	Type
Compressor	Two-stage reciprocating compressor or screw type with economiser. Size: all.
Condenser	Evaporative.
Receiver	Fitted.
Expansion device	Usually float valve. Sometimes thermostatic expansion valve.
Evaporator	Flooded, floor-mounted finned tube-type.
Refrigerant	Usually ammonia. Sometimes R22.
Additional components	Pumping station and oil management system. Large systems may use a two-stage refrigeration system with multiple compressors.

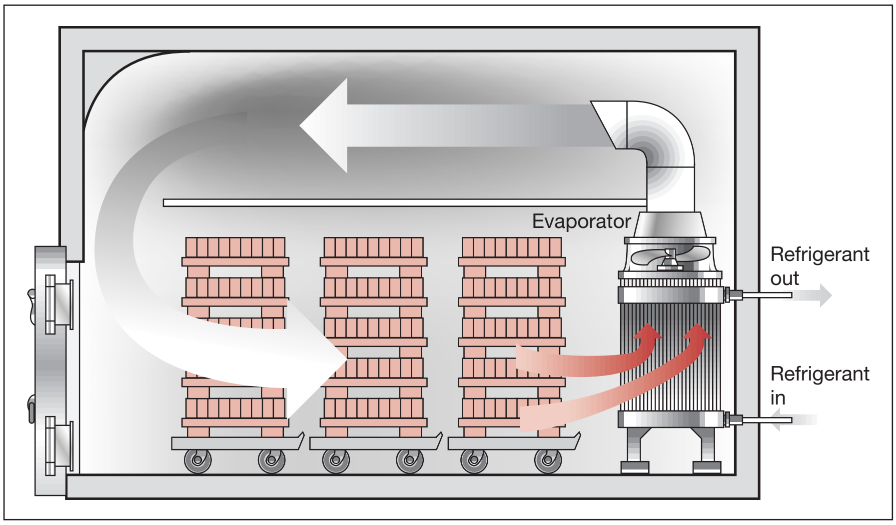


Figure 34 Diagram of a blast freezer system (batch throughput)

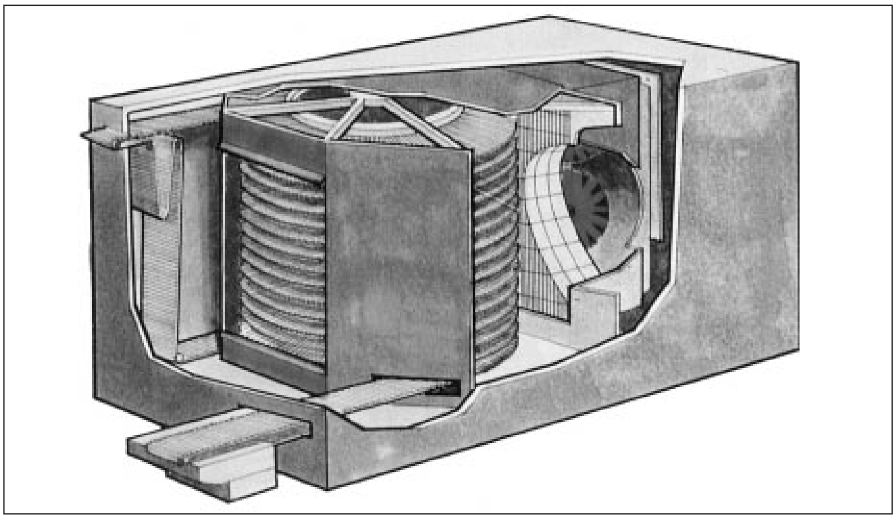


Figure 35 Cutaway diagram of a single-drum spiral freezer (continuous throughput) Courtesy of Jackstone Food Systems

Specific efficiency issues for blast freezers

- **Ensure air flow does not bypass the product.**
- **Maintain air velocity below 3 m/s (higher velocities require more fan motor power for little improvement in cooling effect).**
- **Ensure minimum ingress of air/moisture.**
- **Minimise internal heat loads during the freezing period.**
- **Ensure effective defrost.**
- **Ensure optimum product throughput rate (too short means un-frozen product, too long means excessive run-times).**
- **Where possible, maximise air cooling of product at higher evaporating temperatures prior to entry into the tunnel.**

3.8 Low temperature applications and two-stage systems

Applications requiring low evaporating temperatures, such as ice cream hardening at -45°C, or storage of frozen products at -35°C, result in correspondingly low pressures at the compressor suction, which means a very high overall compression ratio. For practical and efficiency reasons this can be met by:

- a two-stage reciprocating compressor system with an intercooler;
- a two-stage screw compressor system, preferably with an intercooler;
- a single-stage screw compressor, preferably with an economiser.

These alternatives are described below.

Using reciprocating compressors

In low-temperature applications, using a reciprocating machine to compress the vapour in one ‘squash’ from a low suction pressure up to the condensing pressure is ineffective. This is because the compressed gas left in the clearance volume at the end of the compression stroke would re-expand on the down stroke, and leave little room for drawing in more suction gas for the next stroke. In addition, compression over a wide pressure differential can cause excessive discharge temperatures. For these reasons, the compressor manufacturers set operating limits for single-stage operation which are refrigerant dependent (usually of the order of 10:1). For low-temperature applications, compression has to be carried out in two stages.

In between the two stages of compression, it is necessary to cool the refrigerant gas to avoid compressor failure. On smaller systems, this can be done by injecting liquid refrigerant leaving the condenser directly into the refrigerant gas between stages. The alternative is to use an intercooler, which achieves the cooling of inter-stage gas using a pool of refrigerant at an intermediate pressure and temperature.

There are two additional benefits to using an intercooler:

- it subcools the liquid going to the low-temperature evaporators, which reduces the work that the low-stage compressors are required to do;
- higher temperature cooling loads can be served from the intercooler and hence by the high-stage compressor only – reducing the load on the low-stage machines.

There are two types of intercooler.

a) Open-type intercoolers

The simplest type of intercooler is an open pressure vessel (i.e. nothing inside), with an HP or LP float valve admitting the liquid refrigerant from the condenser. The hot gas from the first stage of compression is bubbled through the liquid, and thus cooled. The second (high) stage compressor draws its gas from the intercooler. This type of intercooler has the advantage that all the refrigerant liquid passes through it, and thus is subcooled to the intercooler temperature before the evaporator. The disadvantages of this type of intercooler are:

- for systems with widely or rapidly varying loads, the level in the intercooler can be hard to control;
- liquid refrigerant passes through two expansion valves before reaching the evaporator, both sized for the whole refrigerant flow.

b) Closed-type intercoolers

In a slightly more complex arrangement of an intercooler (closed-type), most of the liquid flowing from the condenser passes through a coil submerged in a bath of liquid in the shell of the intercooler. A small proportion of the liquid flowing from the condenser is bled off to maintain the liquid bath. This bath is constantly being evaporated by the heat given up, by both:

- the high-pressure ‘hot’ liquid flowing through the coil (being subcooled prior to flowing to the low stage);

- the superheated gas from the first stage of compression bubbled through the pool of liquid to cool (i.e. de-superheat) it prior to entering the high-stage cylinders.

The closed-type intercooler is less sensitive to load changes than the open-type unit. The liquid passes through only one expansion valve, thus most of the pressure differential between the condenser and evaporator is available across the evaporator expansion valve. In the open type it expands twice; initially from condensing pressure to intermediate pressure, and finally, from intermediate pressure to evaporating pressure. With the closed-type unit, the liquid is subcooled, usually to within 5°C of the intermediate saturation temperature. Liquid leaves the shell side of an open-type intercooler, saturated, at a temperature equal to the intermediate saturation temperature.

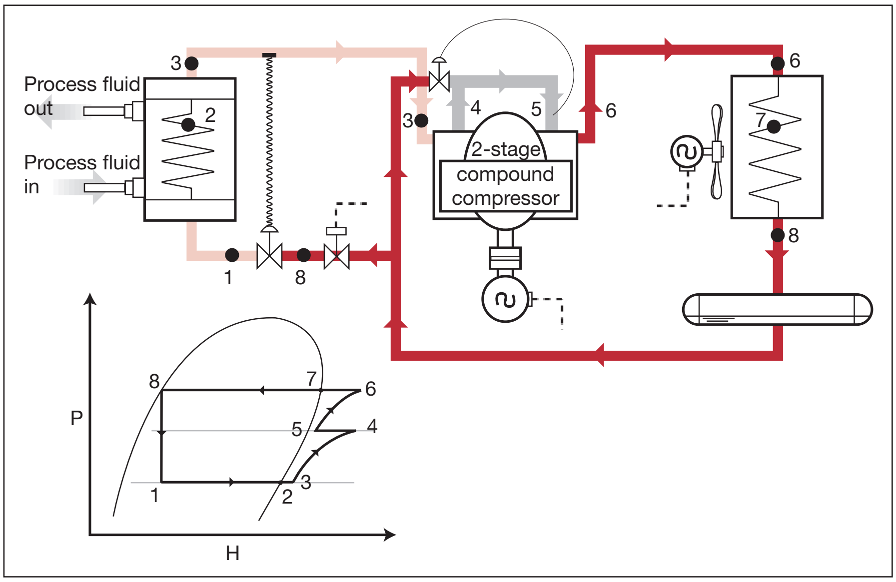


Figure 36 Schematic diagram of a simple two-stage system with an internally compounded compressor

Two of the most common types of two-stage (or compound) systems are shown in Figures 36 and 37.

This basic system (Figure 36) solely addresses the problem of high vapour temperature at minimum capital cost. A minimum level of condensing pressure must be maintained. The inter-stage pressure may not be most efficient for a specific application.

The system in Figure 37 provides an increase in energy efficiency primarily by subcooling the liquid going to the evaporators, usually to within 5°C of the inter-stage saturation temperature. This system also ensures full de-superheating of the low-stage discharge. It enables side loads (i.e. higher temperature loads) of any magnitude to be supplied at intercooler temperature, or allows the optimum inter-stage condition to be utilised. The capital cost, however, is relatively high.

Using screw compressors

See screw compressors page 15

A screw compressor can operate at higher pressure ratios as it has a relatively small clearance volume and so will be able to handle in a single compression a pressure difference which would require two stages for reciprocating compressors. However, an economiser circuit (also called a liquid subcooler) can increase its capacity and improve efficiency. An economiser is a heat exchanger which, like the intercooler described above, uses a pool of liquid refrigerant at intermediate temperature and pressure to cool the liquid going to the evaporators. This increases the compressor capacity and its efficiency. The gas generated in the economiser is taken to an intermediate pressure tapping on the casing of the screw compressor. Economisers, like intercoolers, are available as open and closed types, and will provide all of the benefits of liquid subcooling, but no gas intercooling is required and so the vessels are smaller. For the ‘open’ type of economiser, care is required to ensure that sufficient pressure is available for the low-stage expansion valve to operate properly.

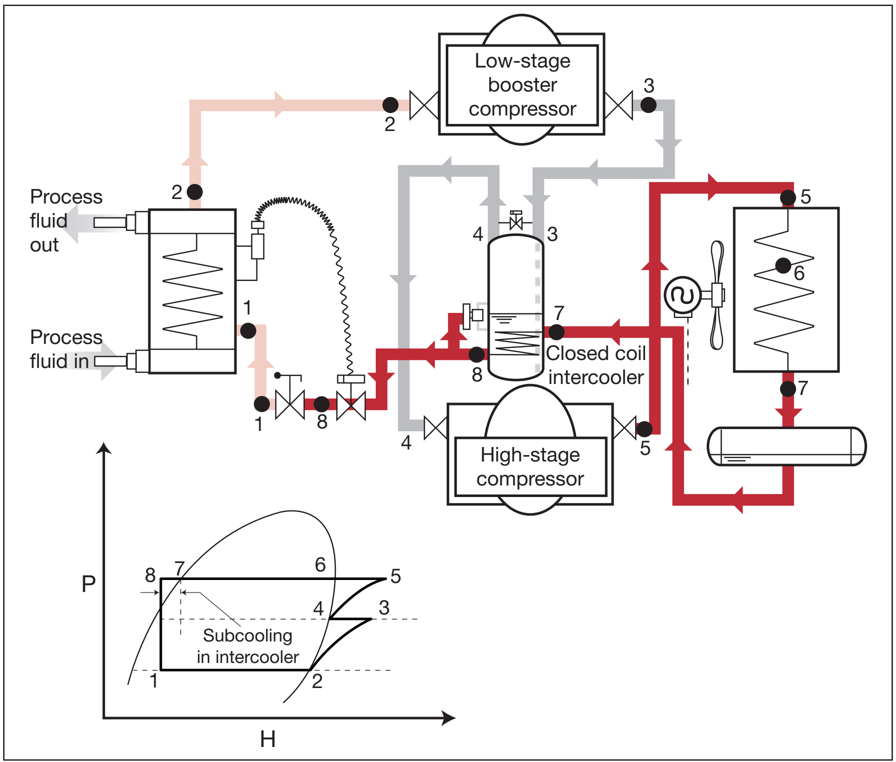


Figure 37 Two-stage system – externally compounded. Shows booster stage and high-stage compressors with closed coil intercooler

Two-stage operation of screw compressors can also bring improvements in energy efficiency for high compression ratio systems and so should be investigated.

Key efficiency issues for low temperature applications and two-stage systems

- **Select the inter-stage pressure to give optimum efficiency – this can mean set it as high as possible to suit intermediate temperature loads or, in the absence of these, at the optimum thermodynamic point (given by $\sqrt{(\text{condensing pressure x evaporating pressure})}$, where the pressures are in absolute units).**

- **Ensure maximum subcooling of high-pressure liquid is achieved (typically the inter-stage equivalent saturation temperature for open intercoolers, or within 5K higher for the closed-type).**

- **For large heat loads with different product temperatures, consider separate low-pressure machines for each temperature level, discharging to a common intercooler.**

Cascade sytems

On very low temperature applications, the differential between the evaporating pressure and the condensing pressure can be minimised by employing a cascade system of operation.

In such a system, the low-temperature circuit operates on a refrigerant selected to give an adaquate pressure at the very low evaporating temperature required by process, while the high-stage circuit operates on a refrigerant selected to give, at the condensing temperature dictated by the cooling medium available, a normal condensing pressure. The condenser of the low-temperature circuit is the evaporator of the high-stage circuit (see GPG 283 *Designing energy efficient refrigeration plant*).

See
GPG 283

A

GLOSSARY OF TERMS

Absorption Cycle	A refrigeration cycle based on absorption of low-pressure vapour into an absorbing fluid. No compressor is required, although a liquid pump is usually employed. The cycle is usually driven by heat input.
Air Conditioning	The process of modifying/controlling the temperature and humidity of air. It usually refers to situations where air needs to be cooled (and/or moisture removed).
Air Cooler	A heat exchanger for cooling air, usually in a chill or cold store.
Air Purging	The process of removing unwanted air (and other non-condensable gases) from the condenser of a refrigeration plant.
Ambient Temperature	The dry bulb temperature of the outdoor air.
Ammonia (NH_3)	A primary refrigerant used in many industrial refrigeration systems. Refrigerant R717.
Base Load	The level of cooling load that represents the minimum load under normal operating conditions.
Bespoke	A refrigeration plant specifically designed for an end-user application (as opposed to a packaged plant, which is of standard design).
Brine	A general term for a secondary refrigerant. It usually refers to calcium chloride brine, which is a solution of calcium chloride and water.
Capacity Control	A system to reduce the cooling capacity of refrigeration plant.
Cascade Cycle	A specialised refrigeration cycle design used for very low temperature applications. It consists of two or more separate refrigeration circuits, each using a different refrigerant. The heat rejected by a first-stage condenser is absorbed into the evaporator of the next stage in the cascade.
CFC	Chlorofluorocarbon. This is a type of refrigerant consisting of chlorine, fluorine and carbon. CFCs are no longer produced.
CFC Phase-out (strategy for)	The manufacture of CFC refrigerants was banned in 1995. Users of CFCs require a strategy for phase-out that involves either conversion of an existing plant to a new refrigerant or replacement with completely new plant.

Chilled Water	Refrigerated water, often used as a secondary refrigerant to transfer 'cold' to end-user processes.
Coefficient of Performance (COP)	The ratio of the cooling capacity to the absorbed power of a compressor. A key measure of compressor efficiency.
Coefficient of System Performance (COSP)	The ratio of the cooling capacity to the absorbed power of the whole refrigeration system. This measure includes the effect of the power consumption of auxiliary components such as fans and pumps, as well as the compressor. The measure of plant efficiency.
Compression Ratio	The ratio of compressor discharge pressure to suction pressure, using pressure measured in absolute units.
Compressor	A machine which raises the pressure, temperature and energy level of a refrigerant vapour.
Compressor Energy Efficiency	A measure of the energy efficiency of a compressor. It is the ratio of the power that would be used in an 'ideal' or isentropic compressor to the actual power used.
Condenser	A heat exchanger in which a refrigerant vapour gives up heat, cools and then condenses to liquid form.
Condensing Temperature and Condensing Pressure	The temperature and pressure at which the refrigerant condenses to liquid form.
Cooling Duty	The instantaneous cooling load of a refrigeration system.
Cooling Tower	A device used to cool water through the process of partial evaporation.
Defrost	Removal of frost or ice from the surface of an evaporator.
Defrost on Demand – Control	A control system that automatically initiates an evaporator defrost sequence when an appropriate amount of ice has built up on the evaporator surface.
De-superheater	A heat exchanger used to remove sensible heat from compressed vapour prior to it entering the condenser.
Direct Expansion (DX) Evaporator	An evaporator in which all the refrigerant supplied to each parallel circuit completely evaporates in that circuit, producing superheated vapour at the outlet.
Discharge	The high pressure exit from a compressor.
Dry Bulb Temperature	Temperature measured with a dry bulb thermometer. This measures the actual temperature of the air, as opposed to a wet bulb thermometer (see below).
Economiser	A heat exchanger used in certain refrigeration cycles to improve the COP by allowing some refrigerant vapour to be compressed over a reduced compression ratio. It is usually used on screw compressor systems with an intermediate injection port.
Electronic/Computer Control	The use of modern electronic systems for the control of refrigeration plant.
Electronic Expansion Valve (EEV)	An expansion valve controlled by a microprocessor and able to operate under relatively low and varying conditions of pressure difference.

Evaporating Temperature and Evaporating Pressure	The temperature and pressure at which the refrigerant evaporates.
Evaporative Condenser	A condenser in which refrigerant within tubes is cooled by a falling water spray and a counter-current flow of air.
Evaporator	A heat exchanger in which a liquid refrigerant vaporises thus producing a cooling effect.
Evaporator Fans	The majority of air coolers use forced convection and hence require a fan to drive air across the evaporator surface. Evaporator fan power consumption is often a significant proportion of the total annual energy consumption of cold stores and blast freezers.
Expansion Valve	A valve through which liquid refrigerant passes and reduces in pressure and temperature.
Fault Diagnosis	The process of using monitoring data to identify operating problems in a refrigeration system.
Finned Coil	A general term for a heat exchanger transferring heat between a liquid and a vapour. It utilises a finned extended surface on the vapour side. Finned coils are often used for air-cooled condensers or DX air coolers.
Floating Head Pressure	A refrigeration system that allows the head pressure to vary in line with ambient temperature conditions (i.e. a plant that does not use head pressure control to artificially hold the condensing pressure at unnecessarily high levels).
Flooded Evaporator	An evaporator in which only partial evaporation takes place, producing saturated vapour at the outlet.
Free Cooling	A method of cooling that does not require refrigeration (e.g. cooling a substance with river water).
Glycol	A type of secondary refrigerant, usually monopropylene glycol.
Halocarbons	A family of primary refrigerants based on hydrocarbon molecules in which some or all of the hydrogen has been replaced by either fluorine or chlorine. Halocarbons include CFCs, HCFCs and HFCs.
HC	Hydrocarbon. Used as a primary refrigerant.
HCFC	Hydrochlorofluorocarbon. A primary refrigerant of the halocarbon family.
Head Pressure (or Discharge Pressure)	Pressure at compressor outlet. Approximately equal to (and usually synonymous with) the condensing pressure.
Head Pressure Control (or Condensing Pressure Control)	Control of the condenser pressure at a predetermined high pressure (under the prevailing load and temperature conditions).
Heat Exchanger	A device for transferring heat between two physically separate streams.
Heat Pump	A refrigeration cycle used for delivering useful heat from the condenser.
Heat Recovery	Utilisation of ‘waste’ heat from a process (usually to conserve energy).
Hermetic Compressor	A compressor and motor enclosed in an all-welded, leak-proof housing.

HFC	Hydrofluorocarbon. A primary refrigerant of the halocarbon family.
Hot Gas Bypass	A capacity control technique often applied to centrifugal compressors. It is usually wasteful of energy as compressed refrigerant vapour is passed straight back to the compressor suction inlet without performing useful cooling.
HP Float Valve	A type of expansion valve based on the measurement of level in the high-pressure side of the refrigeration circuit.
Isentropic Efficiency	A term that is synonymous with compressor energy efficiency (see above).
Latent Cooling	A method of cooling that involves the evaporation of a liquid (and hence the use of latent heat). Water cooled in a cooling tower is an example of latent cooling.
Lighting (in a Cold Store)	A lighting system suitable for use at low temperature. Many conventional types of lighting equipment cannot easily be switched on at low temperature. Lighting adds to the sensible heat load in a cold store.
LP Float Valve	A type of expansion valve based on the measurement of level in the low-pressure side of the refrigeration circuit.
Monitoring (of Plant)	The process of taking measurements of key operating parameters such as temperatures and pressures in order to appraise the operating state of a refrigeration system.
MVR	Mechanical Vapour Recompression. A technique used in open cycle heat pumps. The latent energy content of low-pressure vapour is utilised by compressing the vapour to a more useful higher condensing temperature.
Oil Separator	A device used to remove oil from refrigerant vapour at the compressor discharge.
Open Compressor	A compressor driven by a separate motor/drive and so requiring a rotating shaft seal to limit refrigerant loss.
Packaged	A refrigeration plant of standard ‘off-the-shelf’ design.
PAG	Polyalkaline glycol. A type of synthetic compressor lubricating oil used on some HFC refrigeration systems.
Part-load Operation	Operation of a refrigeration plant below the peak load capability.
Peak Load	The maximum cooling load encountered in a particular refrigeration application.
Plate Heat Exchanger	A type of heat exchanger, usually used for liquid to liquid or liquid to boiling liquid heat transfer, consisting of plates in a frame.
POE	Polyol ester. A type of synthetic compressor lubricating oil used on most HFC refrigeration systems.
Primary Refrigerant	The working fluid of the refrigeration system which absorbs heat in the evaporator and rejects heat in the condenser.

Pumps (Secondary Refrigerant)	Liquid pumps that are used to pass secondary refrigerant from the refrigeration plant evaporator to the process where cooling is required.
Purging	Removal of air or non-condensable gases from the high-pressure side of the refrigeration circuit.
Receiver	A vessel used to store refrigerant within a refrigeration circuit. The most common are high-pressure receivers, located after the condenser. Some systems also utilise low-pressure receivers, located before the compressor suction.
Refrigerant Leakage	Most types of refrigeration system are prone to some degree of refrigerant leakage. This can cause excessive energy consumption, damage to the environment and loss of cooling capacity.
Saturated	A thermodynamic term referring to a fluid at a temperature equal to the boiling point at the prevailing pressure. A saturated liquid is just about to boil or has condensed and a saturated vapour is just about to condense or has just evaporated.
Secondary Refrigerant	A fluid which is cooled in the evaporator by heat exchange with the primary refrigerant and then circulated to provide cooling of remote loads (also known as a ‘heat transferring fluid’).
Semi-hermetic Compressor	A compressor directly coupled to an electric motor. Compressor and motor are contained within a single enclosure, sealed at a gasketed, flanged joint by bolts.
Sensible Cooling	A method of cooling that does not involve evaporation of a liquid (as opposed to latent cooling, see above).
Shell and Tube Heat Exchanger	A type of heat exchanger involving a nest of tubes within a baffled shell.
Single-stage Cycle	A refrigeration cycle using one stage of compression.
Specific Energy Consumption	A measure of the energy consumption of a refrigeration plant compared to some product-related quantity. For example, the amount of energy used per tonne of product cooled.
Specific Refrigerant Charge	The ratio of the amount of refrigerant contained within a system to the cooling capacity, usually measured in kg/kW.
Subcooled Liquid	A thermodynamic term referring to a fluid at a temperature below the boiling point temperature at the prevailing pressure.
Subcooler	A heat exchanger used to reduce the temperature of condensed liquid below the current saturation temperature.
Suction	The entry point for vapour into a compressor.
Superheated Vapour	A thermodynamic term referring to a vapour at a temperature above the boiling point at the prevailing pressure.
Surge Drum	A vessel used to prevent liquid refrigerant entering the suction of a compressor. (Also known as a Suction Accumulator on small systems.)
Temperature Lift	The temperature difference between the evaporating and condensing temperatures.
Temperature Range	The temperature reduction of the cooled stream across the evaporator.

TEWI	Total Equivalent Warming Impact. The TEWI for a given system represents the sum of the Direct Global Warming caused by probable leakage of the refrigerant and the Indirect Global Warming caused by the release of carbon dioxide from power stations supplying the refrigeration plant with electricity.
Thermal Storage	A system used to store ‘cold’ for use at some future time. For example, an ice bank builds ice slowly during the night and subsequently delivers useful cooling during peak load conditions.
Thermostatic Expansion Valve (TEV)	A valve which regulates the flow of refrigerant into the evaporator in response to the variations of superheat of the refrigerant leaving the evaporator against a preset value.
Thermo-syphon	A type of natural circulation where the boiling of a fluid also causes circulation of that fluid around the circuit through buoyancy forces. In some designs, the thermo-syphon technique is used to provide free cooling.
Two-stage Cycle	A refrigeration cycle using two stages of compression.
Vapour Compression Cycle	A type of refrigeration cycle using a compressor to remove low-pressure vapour from an evaporator and deliver it to a condenser at a higher pressure.
Variable Speed Drive (VSD)	An electronic device used to vary the speed of an electric motor and also known as a Power Inverter.
Volumetric Efficiency	The ratio of the amount of vapour volume pumped by a compressor to the swept volume of the compressor.
Water Chiller	A refrigeration system used to produce chilled water.
Water-cooled Condenser	A heat exchanger used to condense refrigerant vapour using cooling water.
Wet Bulb Temperature	Temperature measured with a wet bulb thermometer. Because the bulb is covered in a film of water, evaporation causes a lowering of the measured temperature if the air humidity is below 100%. Hence, the wet bulb temperature can, in conjunction with a psychrometric chart, be used to establish relative humidity.

B

USEFUL CONTACTS

The following is a list of useful contacts for further information on refrigeration and air conditioning.

American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE)
1791 Tullie Circle, NE, Atlanta, GA 30329-2305, USA.
Tel: +1 404 636 8400 Fax: +1 404 321 5479
Internet Home Page: www.ashrae.org

Building Research Establishment (BRE)
Bucknalls Lane, Garston, Watford, Hertfordshire WD2 7JR
Tel: 01923 664000 Fax: 01923 664790

BRECSU
Building Research Establishment, Garston, Watford, Hertfordshire WD2 7JR
Tel: 01923 664000 switchboard
Tel: 01923 664258 enquiries bureau
Fax: 01923 664787
E-mail: brecsuenq@bre.co.uk

BRECSU manages the Government's Energy Efficiency Best Practice Programme for buildings applications, including air conditioning.

Federation of Environmental Trade Associations (FETA)
Henley Road, Medmenham, Marlow, Buckinghamshire SL7 2ER
Tel: 01491 578674   Fax: 01491 575024
E-mail: info@feta.co.uk
Internet Home Page: http://www.feta.co.uk/

This federation comprises a number of independent but related associations allied to the refrigeration and air conditioning industry, including the BRA and the Heat Pump Association.

British Refrigeration Association (BRA)
Henley Road, Medmenham, Marlow, Buckinghamshire SL7 2ER
Tel: 01491 578674   Fax: 01491 575024
Internet Home Page: http://www.feta.co.uk/

The BRA is a trade association for suppliers of refrigeration equipment and services. It has sections for designers, manufacturers, distributors and installers of components and systems and also for users. The BRA has an active interest in training.

British Standards Institution (BSI)
389 Chiswick High Road, London W4 4AL
Tel: 020 8996 9000 Fax: 020 8996 7400

The BSI publishes a complete range of British Standards covering the manufacture, installation, testing and safety of refrigeration systems and components. A BS number followed by EN indicates that the Standard is also a Euronorm.

Building Services Research and Information Association (BSRIA)
Old Bracknell Lane West, Bracknell, Berkshire RG12 7AH
Tel: 01344 426511 Fax: 01344 487575
Internet Home Page: http://www.bsria.co.uk

Chartered Institute of Building Services Engineers (CIBSE)
Delta House, 222 Balham High Road, London SW12 9BS
Tel: 020 8675 5211 Fax: 020 8675 5449
Internet Home Page: http://www.cibse.co.uk

CIBSE produces Codes of Practice for the installation and commissioning of refrigeration and air conditioning systems.

Cold Storage and Distribution Federation
Downmill Road, Bracknell, Berkshire RG12 1GH
Tel: 01344 869533 Fax: 01344 869527

Department of Trade and Industry
Environmental Division, 151 Buckingham Palace Road, London SW1W 9SS
Tel: 020 7215 1018

The DTI publishes a number of booklets regarding environmental aspects concerning the refrigeration and air conditioning industry. It has also published market studies into the use of refrigerants.

Health and Safety Executive (HSE)
HSE publications are available from:
HSE Books, PO Box 1999, Sudbury, Suffolk CO10 6FS
Tel: 01787 881165 Fax: 01787 313995

The HSE publishes a wide range of books and information leaflets regarding regulations concerning safety in all branches of commerce and industry. All HSE priced publications can be bought from any Stationery Office Bookshop or their agents (see Yellow Pages).

The Heating and Ventilating Contractors' Association (HVCA)
ESCA House, 34 Palace Court, Bayswater, London W2 4JG
Tel: 020 7229 2488 Fax: 020 7727 9268

The Institute of Refrigeration (IoR)
Kelvin House, 76 Mill Lane, Carshalton, Surrey SM5 2JR
Tel: 020 8647 7033 Fax: 020 8773 0165
E-mail: instor@ibm.net
Internet Home Page: http://www.ior.org.uk

The IoR is the professional body of the refrigeration industry. It provides information to the industry through published papers, seminars, Codes of Practice etc.

Local Refrigeration Societies
Local societies run monthly meetings in their areas throughout the winter period. They are usually of a practical nature, aimed at providing information to application, installation and service technicians.

Local societies are run for:

Scotland – Glasgow; South West – Bristol; Northern Ireland – Belfast; East Midlands – Grimsby; East Anglia – Norwich; North West – Liverpool; Yorkshire – Huddersfield, and London.

Contact the IoR (above) for details.

C

SPECIFICATIONS, CODES OF PRACTICE AND REFERENCE SOURCES

Publications from the Institute of Refrigeration

Safety Code for Compression Refrigerating Systems Utilising Ammonia
Part 1: Design and Construction.

Safety Code for Compression Refrigerating Systems Utilising Ammonia
Part 2: Commissioning, Inspection and Maintenance.

Safety Code for Compression Refrigerating Systems Utilising Chlorofluorocarbons
Part 1: Design and Construction.

Safety Code for Compression Refrigerating Systems Utilising Chlorofluorocarbons
Part 2: Commissioning, Inspection and Maintenance.

Cold Store Code of Practice
Part 1: Design and Construction of Cold Store Envelopes.

Cold Store Code of Practice
Part 2: Design and Construction of Refrigerating Systems.

Code of Practice for the Minimisation of Refrigerant Emissions from Refrigeration Systems.

Also sets of technical papers covering the proceedings of past seminars and conferences.

Available from the IoR (see Appendix B).

British Standards

BS4434:1995	Safety and environmental aspects in the design, construction and installation of refrigerating appliances and systems.
BS7671:1992	Requirements for electrical installations – IEE Wiring Regulations, Sixteenth Edition.
BS EN 60529:1992	Specification for degrees of protection provided by enclosures (IP code).

Available from BSI (see Appendix B).

ASHRAE Guides

ASHRAE produces handbooks (in hard copy and electronic versions) covering all aspects of refrigeration and air conditioning and self-directed learning courses. They are available to non-members. Products include:

1997 Handbook – Fundamentals (SI)
1998 Handbook – Refrigeration (SI)
1999 Handbook – HVAC Applications (SI)

Available from ASHRAE (see Appendix B).

BRA Publications

Guideline Methods of Calculating TEWI

The BRA also publishes Fact Finder sheets dealing with topical issues and recommended procedures. Available from BRA (see Appendix B).

CIBSE Guides

A series of substantial CIBSE reference guides is available, with more in preparation. Contact CIBSE for details (see Appendix B).

TRADE JOURNALS

Refrigeration and Air Conditioning (RAC)

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AC&R News

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ACR Today

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Battlepress Ltd, Nithsdale House, 159 Cambridge Street, Aylesbury, Buckinghamshire HP20 1BQ
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Further information

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Building Research Establishment
Garston, Watford, WD2 7JR
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Fax 01923 664787
E-mail brecsuenq@bre.co.uk

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Future Practice: reports on joint R & D ventures into new energy efficiency measures.

General Information: describes concepts and approaches yet to be fully established as good practice.

Fuel Efficiency Booklets: give detailed information on specific technologies and techniques.

Energy Efficiency in Buildings: helps new energy managers understand the use and costs of heating, lighting etc.